2004

Using Autonomous Robots to Integrate Middle School Academic Standards, Technology Standards, and 21st Century Workplace Skills

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By

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A dissertation submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy

The Graduate School of Computer and Information Sciences
Nova Southeastern University

2004

We hereby certify that this dissertation, submitted by Barbara M. Burckart, conforms to acceptable standards and is fully adequate in scope and quality to fulfill the dissertation requirements for the degree of Doctor of Philosophy.

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An Abstract of a Dissertation Submitted to Nova Southeastern University in Partial Fulfillment of the Requirements for the Degree of Doctor of Philosophy

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June 2004

The amount of knowledge that students are required to master continues to grow. Teachers struggle to find age appropriate ways to integrate state academic standards, technology standards, and 21st century workplace skills. Improved problem solving skills are deemed important to these standards as well as in the workplace. This dissertation utilized a robot design project to examine the changes in problem solving skills of seventh grade science students. In the process, 21st century workplace skills, technology standards, and South Carolina middle school science and math standards were identified and integrated into the learning process.

To test the validity of the study, a combination of a descriptive/nonequivalent control group design was utilized. One seventh grade science class was pre-tested using the Test of Adult Basic Education-Problem Solving (TABE- PS), participated in the robotics project and post-tested using an equivalent form of the TABE-PS. A similar class served as a control group. They were pre-tested using the same assessment tool, participated in the traditional science class and finally, post-tested. Descriptive data collected during the project were evaluated using a standardized rubric.

The robot design project consisted of nineteen 85 minute classes and was divided into three sections: introduction to robotics and programming, a series of robotic "missions" where students refine programming and robotic construction skills and a final showcase project where students programmed, designed, and constructed vehicles that competed in a drag race.

T-tests of independent samples indicated that there was a general trend for overall improvement in student problem solving skills; however, the difference between the control and experimental groups' scores was not significant. Four sub-scores of problem solving abilities were examined. These include:

1. Employing reading and math skills to identify and define a problem.
2. Examining situations using problem-solving techniques.
3. Making decisions about possible solutions to a problem.
4. Evaluating outcomes and effects of implementing solutions.

Additional *t*-tests of independent samples indicated that there was no significant difference between the scores of experimental and control groups for sub-scores 1-3. The experimental group did show significant improvement in their ability to evaluate outcomes and effects of implementing solutions over the control group.

Evaluation of student work using the Student Individualized Performance Inventory (SIP) indicated that student problem solving skills improve as they become more familiar with programming and robot construction. Two areas of student weakness emerged from this analysis. Documentation of the technical work completed was weak as was the student use of available reference material. Rubric scores also indicated a correlation between the scores of the individuals in the group and the performance of the robot. Simply stated, groups whose individuals had higher mean scores constructed robots that performed better.

This work provides teachers with a model of how they can integrate state specific content standards with quality experiences that help students to become effective learners in school and the workplaces of tomorrow. This research provided evidence that use of high-interest, developmentally appropriate programming and robotic design activities can begin to improve student problem solving abilities. While helping students improve, teachers will also satisfy the directives of their state, the United States federal government, and employers of the future.

Acknowledgments

Completion of this work was possible because of the encouragement and support provided by my professors, colleagues, and family. My dissertation advisor, Dr. Trudy Abramson was always generous with her time and unfailing in providing frank and valuable advice. Thank you Dr. Abramson for setting me straight and encouraging me the times I began to stumble. I will always be indebted to you for your kindness, wisdom, and graciousness.

Dr. Steve Terrell and Dr. George Fornshell served as members of my dissertation committee and strengthened my work by offering advice based on their professional experience. Drs. Terrell and Fornshell, I will always be grateful for the fresh insights you provided.

There was a time when preliminary work on this dissertation was proceeding but it appeared as though securing the required materials might prove to be problematical. Two colleagues, Sybil Lauderdale and Jim Alberto stepped forward and provided the necessary support. For your demonstration of true friendship I will always be thankful.

Without the love and support of my family this would have been a long, lonely journey. I began this work just as my children were approaching young adulthood. Missy and Glenn, I thank you for being my cheerleaders and for encouraging me to become Dr. Mom. My husband Glenn has always encouraged me to pursue my dreams. Glenn, you've always been there to listen and to provide a different perspective. You've always been there to pick up all the little, mundane, daily things that I sometimes let slide so that I could pursue my dream. You've done so many kind and supportive things through the years I can only say thank you and I love you.

All the supportive efforts have changed me forever. You have all become part of me and I thank you.

Table of Contents

List of Tables

Tables

List of Figures

Figures

Chapter 1

Introduction

Few Americans doubt that adolescents love technology. Cell phones, CD players, computer games, Web surfing, e-mail, text messaging, and instant messaging are interwoven into their daily lives. Adolescent interest in technology is not new. As early as 1997, the Gallup Organization reported a high amount of teen interest and reliance on technology. In contemporary society, the ubiquity of computers is even greater. Teenagers continue to use it at school and at home and have expanded its use to include wireless networks. Though the tools change, adolescents continue to communicate, play, learn, and form relationships just as they did in previous generations. It is paradoxical that even as reliance on technology continues to increase, Americans embrace it without understanding how or why it works (Pearson & Young, 2002).

Broadly defined, technology is "the process by which humans modify nature to meet their needs and wants" (Pearson & Young, 2002, p. 2). Most people think of technology as artifacts like computers, software, aircraft, and nuclear power plants. While this is true, an equally important aspect of technology is to understand the processes required in making and operating the artifacts. These processes include knowing how to engineer a product. Design, problem solving, manufacturing, repair, and equipment operation skills are part of these processes and are important in the workplace. Finally, technology includes knowledge of the infrastructure required for production of technological artifacts. Engineering schools, manufacturing plants, corporate headquarters, and maintenance facilities are part of this infrastructure (Pearson & Young, 2002).

This study utilized the Lego Mindstorms for Schools robot design system to examine the changes in problem solving skills of middle school science students. Twenty-first century workplace skills, technology standards, and South Carolina middle school science and math standards were identified and integrated into the learning process. The final product provides a flexible model that includes technology literacy goals and desirable workforce skills in an educational environment that meets federal and state mandates.

Problem Statement

Americans charge their public school systems with the job of preparing students to be productive citizens in tomorrow's society. Various segments of society have different expectations as to exactly what this means. Parents expect schools to guide children in the development of skills that prepare them to enter the future workplace or advance to higher levels of education. Employers expect employees to be honest, reliable, literate, and able to reason and solve problems, communicate, make decisions, and learn. Communities expect good, productive citizens. The nation's leaders view technology as a tool that is necessary if K-12 educators are to meet all these expectations (International Society for Technology in Education (ISTE), 1998).

Teachers are on the front lines of delivering quality educational experiences that meet the varied expectations of society as well as the specific curriculum demands of their states. The District of Columbia and every state have or are setting curriculum standards that teachers are bound to teach (American Federation of Teachers (AFT), 2001). Forty-nine states are setting standards in English, science, math, and social studies. The fiftieth state, Rhode Island is setting standards in English, science, and math

(AFT, 2001). For many of these states the standards are specific and grounded in detailed content areas rather than the skills that are deemed *twenty-first century skills*.

The CEO Forum on Education and Technology (2001) formed a partnership between the educational community and businesses and spent five years deciding on the skills that students will need to be productive workers and contributing citizens in the twenty-first century. They feel that schools must use technology to improve inventive thinking skills including creativity, problem solving, higher order and sound reasoning skills if students are to succeed in the workforce of tomorrow.

Communities continue to spend large amounts on educational technology. Quality Education Data (2003) predicted that Americans will spend nearly six billion dollars on technology during the 2003-2004 school year. As a result, the American public demands that teachers integrate computer and other technology skills into their curricula. The teaching of specific technology applications further complicates the picture because technologies change rapidly by either becoming obsolete or changing when integrated with new applications.

The author is a middle school science teacher who faces the realities of meeting the demands of these expectations on a daily basis. Today's teachers understand the importance of education reform if students are to succeed in the demanding worlds of the twenty-first century. However, there are few concrete examples that model the ways they can change these reform directives into age appropriate, quality experiences that allow students to become effective learners in academia and the workplaces of tomorrow.

Just as teachers are expected to provide students with activities that are rich in technology, content, and work skills, students are expected to master these concepts and skills. The problem for both students and teachers revolves around how education must evolve in order for technology to support the development of content mastery as well as fluency in the use of current and emerging technologies and workplace skills.

Goal

The goal of this dissertation was to create a learning model that illustrates the use of LEGO programmable robots and integrates the ISTE's National Educational Technology Standards for Students (NETS*S, 1998) with South Carolina (SC) middle school science and math standards (South Carolina Department of Education, 2002). The teaching/learning model that resulted from this effort combined the use of LEGO programmable robots with the mastery of age-appropriate problem solving skills in the science and math curriculum.

The problem solving skills were based on Polya's (1957) problem solving methods. Although Polya's work specifically dealt with mathematics education and was described before the days of classroom computer use, the methods and implications are directly applicable to real world technological problem solving. He felt that the general goal of math teaching was to aid students in developing the skills needed for solving a wide variety of problems (Polya, 1969). This problem solving method is divided into four steps: Understand the problem, devise a plan, carry out the plan, and look back and examine the solution (Polya, 1957).

To test the validity of the study, a combination of a descriptive/nonequivalent control group (Gay & Airasian, 2000) design was utilized. One seventh grade science class was pre-tested, participated in the robotics project and post-tested. A similar class served as the control. The control group was pre-tested, participated in the traditional science class and finally, post-tested. Initial class sessions included minimal instruction in programming; however, the heart of the project focused on teams of students designing, constructing, and testing robots that met a given set of criteria.

Assessment of student learning in constructivist activities is difficult to measure using traditional tests. For this reason, a combination of researcher field notes detailing interactions with students and student journals were used. The pre-test/post test measure of work related problem solving skills was the Test of Adult Basic Education-Work Related Problem Solving (TABE-PS) (CTB Macmillan/McGraw Hill, 1994).

Relevance and Significance

Mindstorms, LEGO's programmable robotics kits, were released in 2001 (LEGO, 2002a). Previous studies using LEGO products were completed using earlier versions of the LEGO/Dacta or LEGO/Technic product line and did not involve creation of autonomous robots (Lego, 2002b). Several projects using the programmable robots have been developed and are currently in use in engineering and computer courses at universities including Massachusetts Institute of Technology (MIT) (http://web.mit.edu/esg/proj/ic/www/), United States Military Academy (http://www.usma.edu/asee/workshop.htm), Indiana University (http://www.indiana.edu/~legobots/photohistory.html), Tufts University (http://www.ceeo.tufts.edu/College/default.asp), and Case Western Reserve University (http://www.eecs.cwru.edu/courses/lego375/).

The study integrated the national technology standards, state science and math standards, and necessary 21st century workplace skills. A project that incorporates these attributes provides educators with a customizable model that allows them to meet the various directives given to public schools within the United States. Providing an opportunity for middle school students to work within a problem based learning framework to design LEGO autonomous robots goes beyond the typical way that students use technology. Today, they are taught to use e-mail and word processors, and how to look up information on the Web (Resnick, 2002). With this model, they were exposed to problem solving at the analysis and design levels. They gained experience in programming, sensing, control and engineering design early in their academic careers. In the past, only students entering computer or engineering fields would have these experiences. Introducing design centered, problem based learning has the potential for helping them become better thinkers and learners and therefore better citizens, academics, and workers of the 21st century.

Barriers and Issues

One of the important issues related to the study of problem solving is that there are many types of problems that a person must solve within the day's activities. Some categories of problems that a middle school student might face include family problems, social problems within a peer group, academic problems, and technological problems. Clearly, these different types of problems require different skill sets. The literature provides little that contrasts between the different skills needed for personal and technological problem solving.

Research Questions

As a foundation for the investigation, this dissertation examined:

1. Which technology and state science and math standards could be integrated into a programmable LEGO project for middle school students?

2. Which technology-intensive workplace skills could be developed within the project efforts and how could their mastery be measured?

3. How can problem-solving skills including analysis and design be incorporated into the project?

4. How do students' problem solving skills change as a result of participation in the project?

The investigation also examined the current use of autonomous robots in educational settings, the current state of educational standards in South Carolina, and the skills that American society expects its workers to have in the 21st century.

Summary

The LEGO Robolab robotic design system provided students with age appropriate, engaging and interesting materials. This study combined the resulting autonomous robots and a series of design and programming activities. Student problem solving abilities were the focus of investigation throughout the project. Teachers utilizing activities of this type reinforce technology, math and science standards while allowing students to explore their creative design abilities, mechanical engineering skills, computer programming basics, simple system designs, and real life workplace skills.

Table1: Acronyms

Complete Name	Acronym	Page
American Federation of Teachers	AFT	p. 2
Artificial Intelligence	AI	p. 10
Center for Engineering Educational Outreach	CEEO	p. 27
Department of Labor	DOL	p. 20
Developing Cognitive Abilities Test	DCAT	p. 13
Individual Diagnostic Profile	IDP	p. 26
International Society for Technology in Education	ISTE	p.2
International Technology Education Association	ITEA	p. 23
Massachusetts Institute of Technology	MIT	p. 5
National Academy of Engineering	NAE	p. 23
National Council of Teachers of Mathematics	NCTM	p. 15
National Educational Technology Standards for Students	NETS*S	p. 4
National Research Council	NRC	p. 23
National Skill Standards Board	NSSB	p. 20
No Child Left Behind	NCLB	p. 14
Palmetto Achievement Challenge Test	PACT	p. 33
Robotic Invention System	RIS	p. 27
School-to-Work Opportunity Act	STWOA	p. 20
Secretary's Commission on Achieving Necessary Skills	SCANS	p. 17
South Carolina	SC	p. 4
Student Individualized Performance Inventory	SIP	p. 26
Test of Adult Basic Education-Problem Solving	TABE-PS	p. 5

Chapter 2

Review of the Literature

Introduction

The LEGO Company has a history dating back to 1932. Its name was derived from the Danish words "Leg GOdt" meaning "play well" (LEGO, 2004a). The toy lines were developed with the idea of promoting development, imagination, and creativity in children. Papert's 1960s work at MIT led to studying the use of computers with children. Papert's studies of how children learn continues to influence the LEGO philosophy that states optimal learning occurs when children get to explore the world on their own in a guided environment (Lego, 2004b).

During the early 1990s Americans began to call upon schools to prepare students with skills that would serve them well in the working world. By the late 1990s states began to develop sets of core standards that teachers are required to teach. Problem solving skills were deemed important as both workplace and academic skills. Polya (1945) offered a method for teaching students problem solving skills in mathematics. This method has wider applicability than mathematics and is appropriate for use in teaching workplace and technological problem solving skills. Together, these topics formed the theoretical basis for this research.

Children and Computer Programming

The history of computer programming with children stretches back to 1959-1964 when Papert studied at Jean Piaget's Center for Genetic Epistemology in Geneva. In 1964 Papert moved to MIT and changed his focus to the world of Artificial Intelligence

(AI). Piaget's world focusing on the nature of thinking and how children become thinkers is very different from the AI world that focuses on making computers that think (Papert, 1980). At this time Papert was the co-director of the MIT AI laboratory and wanted to bring the AI researchers work on the nature of human intelligence into the world of children. The AI community developed a language called Lisp. In 1967 Papert developed the Logo language based on Lisp as a means to bring a powerful programming language suitable for use with children. Logo was first used during the 1968-1969 school year with a group of seventh grade students. Logo classes replaced their regular mathematics curriculum. This use of the program was the initial confirmation that novices could learn the Logo language (Papert, 1980).

Many people within MIT's AI community contributed to the development of the Logo language. As a programming language Logo had two characteristics that distinguished it from other programming languages. First, Logo was interactive. Novice programmers could immediately see the result of their programming actions because the computer would execute the command immediately. Second, children using Logo would direct the computer to manipulate the movement of a robot rather than simply manipulate data (Martin, 1994).

The first Logo robot was called a floor turtle. At this point it had no graphics and children as young as four years old successfully controlled it using Logo commands. Floor turtles were simple mechanical robots tethered to a computer. (Papert, 1980). The advent of the computer display moved the Logo turtle from the floor to the screen. This change had both advantages and disadvantages over the floor turtle. Screen turtle advantages include the ability to reach more children because they could be used anywhere there was a computer display. Screen turtles could also move rapidly and precisely and did not have the mechanical problems related to a floor turtle. The screen turtle held the disadvantage of being more abstract than the floor turtle. However, children came to understand how to program a turtle and it accelerated the children's ability to relate to programming activities (Martin, 1994).

There is a rich history of LEGO's in education. They have been used with students ranging in age from elementary school through undergraduate engineering classes. The project settings are varied and include museums, after school programs, computer clubhouses, and formal courses. Erickson, Seymour, and Suey (1996) provided teachers with activities to teach mechanical and structural engineering concepts. However, computer programming applications expanded the number of concepts that could be taught.

By the mid 1980's researchers working in Papert's group began experimenting with electronic interfaces that allowed children to attach sensors and motors to the computers running Logo. This project eventually became known as the LEGO/Logo project and resulted in the development of the "LEGO Technic" line of products. Advances in this system included the ability of LEGO builders to manipulate the plastic LEGO pieces into animated mechanical projects. MIT researchers were building interfaces that allowed them to manipulate LEGO creations while the president of the LEGO Company read Papert's (1980) *Mindstorms*. He felt that both the LEGO Company and Papert's group shared a sense of values about the role of children's play in learning and eventually a joint research project emerged. By the late 1980's the LEGO

Company had been selling the educational system that resulted from the collaboration—LEGO tc (Technic control) logo (Martin, 1994).

Resnick, Martin, Sargent, and Silverman (1996), did much of the work on the LEGO tc Logo project began searching for ways to extend the product's usefulness. At this time the kinds of LEGO creations that children could build were limited because the object was tethered to the computer by a wire. They wanted children to be able to create autonomous robots and experimented with remote control technology using infrared or radio receivers. Their research led to the development of the LEGO/Logo Programmable Brick. The Programmable Brick had outputs to control four LEGO motors and four inputs capable of receiving information from sensors. Limitations of the Programmable Brick rendered it unusable without the presence of an expert.

Martin (1994) contributed to the development of a model class for MIT undergraduate engineering students. Students were responsible for conception, design, implementation, debugging, and a competitive demonstration of an autonomous robot. Data were collected from a variety of sources including observations, student journals and written reports, and analysis of student programs and robots. The course culminated with a contest between student constructed robots.

This work was important in the development of the LEGO Programmable Brick, a small computer designed to connect the real world to models via sensors and actuators. In the process of programming the LEGO brick, students transform models into autonomous robots (Resnick, Martin, Sargent, & Silverman, 1996). The Programmable Brick was developed into several research technologies and it became the inspiration for the LEGO RCX Brick.

The LEGO Company designed the RCX Brick as the brain of the robotics system. The RCX Brick runs both the commercial Mindstorms system as well as Mindstorms for Schools. The RCX Brick functions as the brain of the LEGO robot and is capable of communicating with other RCX Bricks and computers (LEGO, 2002a). Appendix A contains the specifics of LEGO electronics and Robolab programming.

Pollock (1997) used a two-quarter LEGO-Logo programming class to investigate the difference in elementary students' cognitive abilities, school attitudes and programming mastery. Because a random group assignment was not possible the researcher designed the study utilizing a pretest/posttest design with an experimental group of students studying LEGO-Logo and a comparison group of students studying French.

The Developing Cognitive Abilities Test (DCAT) measured problem-solving abilities, learning characteristics, and abilities that contribute to academic performance and is now out of print (Aylward, 2002). No significant difference was found in the problem solving skills of the groups studying LEGO-Logo and those studying French. Although general trends of the results were positive, no significant difference was found in either motivation for schooling or the assessment of computer programming achievement.

Wu (2001) investigated the use of computer controlled LEGO/Logo projects to integrate math, science, and technology concepts. Ten fifth grade students participated in a two-month long after school program where they worked in pairs to build a vehicle that used gears, motors, and LEGO blocks to integrate the study of the math concept of ratios with the science concept of gears. The term integration was used to show that math, science, and technology concepts are interrelated and dependent on one another. Integrated learning activities work to provide a holistic program of study where students learn content while they practice solving real world problems. The integrated aspects of learning examined were:

- What the materials and settings provide
- How the students used the materials
- The psychological processes that support linking math, science, and technology concepts together.

The materials and the psychological processes involved supported the integrated learning of math, science, and technology concepts. Also, the design aspects of the project did not require quantitative math reasoning about gear ratios to design effective gear systems. These findings supported the idea that students learn from their projects by considering math, science, and technology concepts together and by thinking about their relationships.

Academic Standards

The No Child Left Behind (NCLB, 2002) legislation requires that all states develop their own academic standards in reading, math, and science. SC, the state where this study was completed, defines content standards as "broad statements of what students are expected to know and be able to do" (College of Charleston, 2003, Definition of Standards section, ¶ 1). Curriculum is based on science, math, reading, language arts, social studies, foreign language, health, physical education, and visual and performing arts standards (SC Department of Education, 2003a). Rather than re-write technology standards, SC adopted the ISTE's standards (SC Department of Education, 2003b). When teachers present instructional activities that simultaneously address the standards of more than one academic area students benefit because both the standards and the relationships between subjects are reinforced.

South Carolina Science Standards

SC middle school science standards are written for grades six through eight and are divided into four broad categories: inquiry, life, earth, and physical (SC Department of Education, 2002). After a careful review, it was determined that the science standards listed in Appendix B would be included in the robotics' project. The bold print indicates South Carolina State Science Standards. Standard print indicates how the standard was integrated into the project

South Carolina Math Standards

SC adopted mathematics standards in 2000 based on the National Council of Teachers of Mathematics (NCTM) Principles and Standards for School Mathematics (SC Department of Education, 2003c). Students can complete Algebra I in the middle school. The math standards included in this project include those written for Grades 6-8. Math standards are divided into process, algebra, geometry, measurement, and data analysis and probability standards. After a careful review it was determined that the math standards listed in Appendix C would be included in the robotics' project. The bold print indicates South Carolina State Math Standards. Standard print indicates how the standard was integrated into the project

Technology Standards

The ISTE (1998) developed the NETS*S as recognition of society's need for citizens that can function in a world that is becoming increasingly more complex and information-rich. Technology standards for students in Grades K-12 are divided into six broad categories:

- Basic operations and concepts
- Social, ethical, and human issues
- Technology productivity tools
- Technology communications tools
- Technology research tools
- Technology problem-solving and decision making tools.

Developmentally appropriate technology skills are targeted and written for Grades K-2, 3-5, 6-8, and 9-12. Although this study involved students in Grade 7, Appendix D includes those skills that are reinforced from earlier years as well as those incorporated from the Grade 9-12 standards. The bold print indicates ISTE technology standards. Standard print indicates how the standards were integrated into the project.

21st Century Workplace Skills

Two major changes occurred during the last quarter of the 20th Century: the globalization of commerce and the technology explosion. By 1994 the Internet was already twenty-five years old; however, governments, corporations, and educational institutions were just beginning to come on-line (Zakon, 2003). In a little less than ten years the Internet rose from obscurity to prominence. Estimates derived from the 2001 U.S. Census indicate that more than half of the nation is online and that more than 90 percent of children between the ages of 5 and 17 use computers (A Nation Online, 2002).

The Internet and other technologies continue to be a strong presence in the lives of most middle school American children. In 2006, a time when these students will be a few years away from entering the workforce, it is expected that nearly one-half of all U.S. workers will be employed in positions that produce or intensively use information technology products and services (21st Century Workforce Commission, 2000).

In 1991, a commission working under the direction of then Secretary of Labor, Lynn Martin, published the still-relevant *Secretary's Commission on Achieving Necessary Skills* (SCANS) report. SCANS was written to help teachers, parents, and employers understand how curriculum and instruction must change if students are to develop the high performance skills needed for successful job performance. A combination of foundation skills, additional competencies and personal qualities are required skills that employers will seek in both blue-collar and white-collar employees (SCANS, U.S. Department of Labor, 1991). The foundation skills update the traditional literacy and computational skills taught in American public schools. It is based on three parts: basic skills, thinking skills, and personal qualities.

Basic skills include reading, writing, math computation and reasoning, listening and speaking. Updated reading skills require more than decoding and comprehension. Employees need to read well enough to interpret diagrams, manuals, charts, graphs, tables and specifications. The ability to read diverse materials allows workers to locate appropriate information so that a decision can be made or a course of action recommended. The project required students to read and utilize LEGO diagrams and Robolab programs to design, construct, and program the robot. Updated writing skills include the ability to prepare correspondence, instructions, charts, graphs, requests, and proposals. In the LEGO project, student journals served as a record of the instructions they wrote and the robot designs they created and refined.

Math and computational skills are required to maintain records, estimate results, and use spreadsheets. This project required that students keep records and estimate the robot's performance and did not require many computational skills.

Listening and speaking skills are also important in today's workplace. Workers must listen and speak well enough to work in a team, solve problems, teach others, and understand the concerns of others. Successful completion of the project required students to consider other's ideas and decide which ideas will provide the best solutions. Convincing other team members that their idea is best required persuasive speaking.

Thinking skills included creative thinking, making decisions, solving problems, seeing things in the mind's eye, and knowing how to learn and reason. Creative thinking means using the imagination, combining ideas and information in new ways and making connections between ideas that seem to be unrelated. Decision-making entails setting goals and constraints, generating alternatives, considering risks and evaluating and choosing between alternatives. Problem solving involves more than just recognizing a problem. It also requires developing and implementing plans of action, evaluating and monitoring progress, and revising the plan as indicated. Seeing things in the mind's eye involves using and interpreting symbols and other information. Knowing how to learn involves recognizing and using learning techniques. Reasoning involves discovery of rules or principles that govern relationships.

The reinforcement and development of thinking skills were the heart of the project. The various aspects of the project required that they use all of the thinking skills listed. Problem solving abilities were measured using the TABE-PS (CTB McGraw Hill, 1994).

Personal qualities necessary for productive work include individual responsibility as well as self-esteem, sociability, self-management, and integrity. Responsibility indicates hard work and high standards, attention to detail, and high levels of concentration, punctuality, good attendance, enthusiasm, and optimism. Sociability includes friendliness, adaptability, empathy, and politeness as well as asserting oneself, relating to others, and taking an interest in others. Self-management includes self-motivation, self-control and response to feedback in a non-defensive and unemotional way. Integrity and honesty imply that one can be trusted and will choose the ethical course of action.

Participation in the project required ethical behavior and other positive personal qualities; however, as in most educational settings they were not directly taught. Attendance was monitored and field notes recorded evidence of both positive and negative personal qualities.

Even when a worker possesses these updated foundation skills more is required if he is to be successful in the workplace of the 21st century. SCANS (U.S. Department of Labor, 1991) used the foundation skills as a basis for developing an additional five competencies to span the void between school and work. These competencies include skills in managing or using:

- Resources
- Interpersonal skills
- Information
- Systems
- Technology

Appendix E includes an explanation of the SCANS Competencies (SCANS, 1991) and how they were integrated into the project.

Beyond SCANS

Many organizations continued the work begun in the original 1991 SCANS document. The Department of Labor (DOL) itself updated its original work in *Learning a Living: A Blueprint for High Performance* (SCANS, 1992). The five competencies and three foundation skills remain the basis on which high performance is built. In addition, the Commission recommended that schools introduce students to workplace know-how by the time they complete middle school and that teachers present learning opportunities in which students learn content while solving realistic problems (Department of Labor, 1992).

Although the skills and competencies considered important in a high performing workforce were identified, there was no framework from which individual states could create statewide school-to-work programs. With that in mind the Congress of the United States enacted the School-to-Work Opportunities Act (STWOA) of 1994. Federal funds were provided to cover start-up costs for implementing the programs. In addition to providing funding, the act focused on coordinating school-based and work-based learning while making the academic learning available to all students. STWOA continued the earlier directive for teachers to provide classroom-based experiences with strong contextual connections to life and workplace applications based on skill standards.

By 1994 the basic frameworks were in place and the National Skills Standards Board (NSSB) was established as a coalition of leaders from business, labor, employee, education, community and civil rights organizations to build a voluntary national system of skill standards, assessments and certifications. NSSB defines "skill standards" as "performance specifications that identify the knowledge, skills, and abilities an individual needs to succeed in the workplace" (Workforce Excellence Network, 2002).

At the same time national legislators were enacting public laws like STWOA and writing industry skill standards, state departments of education were beginning to adopt academic standards. Together, these presented schools with the additional challenge of presenting lessons to students that met both the academic standards and workplace needs. The academic standards, technology standards, and 21st century workplace skills agree that it is important for students to develop their problem solving skills using technology.

Problem Solving

Science, math, and technology standards, society and employers expect students and workers to be effective problem solvers and technologically literate. The basics of modern problem solving methods lie in the work of Polya (1945). As a mathematician with a passion for math education, he taught many classes on how to motivate and teach students how to solve problems. The work of which he was most proud as well as the work for which he is best remembered is his book *How to Solve It* (1945). It was his belief that fundamental to "doing mathematics" is being able to solve problems. The general tactics for solving problems –having the right attitude and being able to attack all kinds of problems –are within the capabilities of primary school students. He based his problem solving techniques on a set of heuristics or mental questions that help a problem solver follow a basic four-step plan. These principles remain the foundation for problem solving techniques today and earned Polya the title "Father of Modern Problem Solving".

More complicated skills are developed in older children (Polya, 1969). Polya (1945) described four basic principles of problem-solving:

- **Understand the Problem.** Students cannot solve a problem that they cannot understand. In order to show that students understand a problem they can draw a figure using suitable notation, or restate the problem in their own words. Restating the problem might include explaining what they view as parts of a problem, stating the unknown, showing the data, and explaining the conditions under which the problem must be solved.
- **Devise a Plan.** Since there are many ways to solve a problem, students must choose a strategy that they will use in solving a problem. Effective planning strategies include guess and check, reasoning, drawing pictures, using models, and being creative and ingenious. Looking at familiar and related problems can be effective for finding connections between what is known and what is unknown. Finally, problem solvers use this information to devise and record a plan that solves the problem.
- **Carry out a Plan.** Problem solvers test the plan devised. They check each step to see if the plan accomplishes the task set forth. If it does not work they will discard it and devise another plan. Accurate records help in proving that the plan correctly solved the problem.
- **Look Back.** Reflecting on work accomplished is an important part of problem solving. Examining what did not work is as important as what did work. Both help problem solvers to predict what strategies to use for future problem solving.

Although it has been almost 60 years since this four-step method was proposed, researchers continue to use it as a basis for problem solving work. Papert (1980) added a step in Polya's problem solving heuristics when teaching students to work with Turtle geometry. Papert suggested looking for something related that you already understand when approaching a problem that needs solving.

In the 1980s science reform gained prominence in the educational community. As part of this reform movement the Commission on Pre-College Education in Mathematics, Science, and Technology stated that "problem-solving skills, and scientific and technological literacy--- [are] the thinking tools that allow us to understand the technological world around us" (Boser, 1993). The SCANS Report (1991), the ISTE's NETS for Students (1998), the 21st Century Workforce Commission (2000), National Academy of Engineering's (NAE) and National Research Council's (NRC) *Technically Speaking* (Pearson & Young, 2002), and the SC Department of Education's mathematics and science standards (2002, 2003c) each list improved problem solving skills as an important goal in education. The International Technology Education Association (ITEA, 2000) agrees that development of problem solving skills is a necessary component of educational reform. ITEA goes a step further than the other organizations mentioned in that they suggest systematic steps to follow when solving a problem. These steps include understanding the problem, devising a plan, carrying out the plan, and evaluating the plan. ITEA'S four step plan is identical to Polya's and affirms its suitability for technology related activities.

Assessment of Problem Solving Strategies: Test of Adult Basic Education-Problem Solving

In response to the SCANS report, CTB Macmillan/McGraw-Hill (1994) constructed the TABE-PS. It is a constructed response test where the examinee constructs individual responses to situations presented. Rather than measure basic reading, writing, math skills, or specific content knowledge the test measures the steps used in solving different kinds of problems.

This test is part of the TABE family of assessments. It can be used as part of a complete battery of tests or as a stand-alone assessment. The TABE-PS is an authentic performance assessment that measures a wide range of problem solving skills using a variety of work related applications. It is intended for use by employers, educators, and training professionals in order to diagnose how an examinee deals with different aspects of problem-solving including defining the problem, examining the problem, suggesting possible solutions, evaluating solutions, and extending the meaning of the solution.

Four competencies judged essential to the problem-solving process are assigned to each step or sub-step in a task. Competencies 1 and 2 measure the examinee's ability to engage in the process and to understand the situation presented. Competencies 3 and 4 examine the ability to complete the problem solving process. The competency framework is:

1. Employs reading and math skills to identify and define a problem

   A. comprehends written material

   B. interprets graphics

   C. applies mathematical concepts

2. Examines situations using problem-solving techniques

    A. asks the right questions

    B. determines relevancy, adequacy of information

    C. uses appropriate models, tools, strategies

    D. recognizes relationships, trends

    E. understands criteria for judging alternatives

3. Makes decisions about possible solutions

    A. determines whether a decision can be made

    B. considers consequences of possible solutions

    C. selects, rejects, proposes solutions

    D. explains reasons for decision, position

4. Evaluates outcomes, effects of implementing solutions

    A. extends meaning, restructures information

    B. integrates solution into existing system

    C. demonstrates learning from problem-solving situation

    D. suggests possible next steps (CTB Macmillan/McGraw-Hill, 1994)

A norming study was performed on the TABE-PS and the two alternate Forms 7 and 8 were statistically linked. Each form of the test contains several tasks with multiple steps. A practice exercise is available to familiarize examinees with the test before they take it.

It is projected that 65% percent of the entry level work force for the next ten years will typically score between grade levels 5 and 9 on standardized reading tests. Because of this projection the difficulty level of reading and math required for the tasks is in the 6.6 to 8.9 grade range.

An Individual Diagnostic Profile (IDP) is used to record an individual's score and profile mastery of the problem-solving competencies. The IDP is an uncomplicated, hand scored document that allows the examiner to obtain reliable data on the examinee's mastery of problem solving skills (CTB Macmillan/McGraw-Hill, 1994).

Student Individualized Performance Inventory (SIP)

Problem solving involves a complex set of thinking skills and activities and occurs in various ways. This project proposes the use of a design-based process to create and program an autonomous robot that performs based on a specific set of criteria. Design is a primary problem-solving approach in the technology based classroom (ITEA, 2000). It involves ideation, identification of possible solutions, prototyping, and finalizing design. Custer, Valesey, and Burke (2001) constructed and validated the SIP (Appendix F), a rubric used to assess individual problem solving in high school problem solving design activities.

The SIP examines four dimensions of technological problem solving. These dimensions are:

- Problem Design & Clarification
- Develop a Design
- Model/Prototype
- Evaluate the Design Solution

Students work in design groups and were rated using the following scale:

1. Novice

2. Beginner

3. Competent

4. Proficient

5. Expert

The SIP was used to assess individual work during the course of the investigation.

LEGO

The LEGO Corporation began building the popular plastic block system in 1932. During the 73 years since their inception they have undergone many transformations. In 1958 the company patented the design for the stud-and coupling system that remains in use today and allows the models constructed to have much more stability. In 1961 the wheel was added and in 1969 the cogwheels were added. These became the basis of the LEGO/Technic line in 1977. It was added for older children to build complex, technical models. By 1986 a computer control was added to the Technic set. The first generation of the LEGO Mindstorms, a programmable building set was introduced in 1998. The current generation of Mindstorms, the LEGO Robotic Invention System (RIS) was brought to market in 2001 (LEGO, 2003).

LEGO Mindstorms for Schools is comprised of both hardware components of a robotics system and ROBOLAB the simple programming language that allows young students to program LEGO models to perform autonomous tasks. ROBOLAB software was developed by the Center for Engineering Educational Outreach (CEEO) at Tufts University, the LEGO Educational Division, and National Instruments (CYR, 2002). The CEEO helps schools integrate math, science, reading, and writing into problem solving engineering design problems.

When using LEGO Mindstorms for Schools it is important to differentiate among the following terms.

- ROBOLAB is the name of the computer software. It is a non-intimidating environment that introduces students to the basics of programming. Icon based commands are used to gradually move students from an introduction to logical sequencing through the use of fail safe templates to flexible, multilevel program construction and scientific investigation through data collection.
- The RCX brick is heart of the system. It is an autonomous microcomputer that is programmed using a computer. The RCX can receive input from sensors, process data, and signal output to motors and lamps. The RCX operating system software is called firmware.
- Infrared transmitters are used to transfer programs from the computer to the RCX brick. The legacy style transmitter is a serial transmitter; however, USB transmitters have been added.

To use the robotics system, users design and build a robot using LEGO elements and the RCX. They write a program using ROBOLAB and download it to the RCX using the infrared transmitter. The robots that result are fully autonomous and capable of interacting with the environment (Cyr, 2002).

Summary

Many aspects of math, science, technology, and engineering education are integrated into this dissertation. Modern problem solving methods date back to 1945 when Polya (1945) explained four basic principles for effective problem solving. These were based on his belief that fundamental to "doing mathematics" is being able to solve problems. Polya's four principles for effective problem solving are:

- **Understand the Problem.** Students cannot solve a problem that they cannot understand. In order to show that students understand a problem they can draw a figure or restate the problem in their own words.
- **Devise a Plan.** Since there are many ways to solve a problem, students must choose a strategy that they will use in solving a problem.
- **Carry out a Plan.** Problem solvers test the plan devised.
- **Look Back.** Reflecting on work accomplished is an important part of problem solving.

By 1959 Papert became interested in a related field of research; the nature of thinking and how children become thinkers. The work continued to evolve and by 1967 a large number of MIT researchers worked under the direction of Papert and developed Logo, a programming language used by children to direct robot movements. By the mid 1980's researchers working in Papert's group began experimenting with electronic interfaces that allowed children to attach sensors and motors to the computers running Logo. This project eventually became known as the LEGO/Logo project and resulted in the development of the "LEGO Technic" line of products. The current version of LEGO Mindstorms for Schools is comprised of both hardware components of a robotics system and ROBOLAB, the simple programming language that allows young students to program LEGO models to perform autonomous tasks.

While these technologies were evolving in the computing and research worlds, American society was also developing a large set of expectations for the public schools of the country. In 1991, a commission working under the direction of the Secretary of Labor published the still-relevant SCANS report. SCANS was written to help teachers, parents, and employers understand how curriculum and instruction must change if students are to develop the high performance skills needed for successful job performance.

Meanwhile, SC, the state where this study was completed, wrote content standards and defined them as "broad statements of what students are expected to know and be able to do" (College of Charleston, 2003). Curriculum is based on science, math, reading, language arts, social studies, foreign language, health, physical education, and visual and performing arts standards (SC Department of Education, 2003a). Rather than re-write technology standards, SC adopted the ISTE standards (SC Department of Education, 2003b).

Science, math, and technology standards as well as the 21st century workplace skills all include the ability to solve problems as an important skill for students to learn. There are few concrete examples for teachers to follow in order to improve student problem solving abilities. This dissertation employed two assessment tools to evaluate the students' problem solving skills. The first assessment tool is the TABE-PS, an authentic performance assessment that measures a wide range of problem solving skills using a variety of work related applications. It is intended for use by employers, educators, and training professionals in order to diagnose how an examinee deals with different aspects of problem-solving including defining the problem, examining the problem, suggesting possible solutions, evaluating solutions, and extending the meaning of the solution (CTB Macmillan/McGraw-Hill, 1994). The second assessment tool is the SIP, a rubric used to assess problem solving in design activities (Custer, Valesey, & Burke, 2001). The SIP examines four dimensions of technological problem solving. These dimensions include Problem Design & Clarification, Develop a Design, Model/Prototype, and Evaluate the Design Solution. Students work in design groups and are rated using the following scale:

1: Novice

2: Beginner

3: Competent

4: Proficient

5: Expert

The use of robot design projects in undergraduate computer and engineering classes is not new. Martin (1994) developed a model class for MIT undergraduate engineering students. Students were responsible for conception, design, implementation, debugging, and a competitive demonstration of an autonomous robot. Data were collected from a variety of sources including observations, student journals and written reports, and analysis of student programs and robots. The course culminated with a contest between student constructed robots. The idea of providing a course where students integrate computer programming with autonomous robot construction provided the inspiration to bring these types of experiences into the middle school classroom.

Chapter 3

Methodology

Introduction

Chapter 1 indicated that this study utilized a LEGO Mindstorms for Schools robot design project to examine the changes in problem solving skills of seventh grade science students. The model resulting from this effort combined the use of programmable LEGO robots with the mastery of age-appropriate problem solving skills.

Problem-solving skill development is a key element of this research project. Appendix G contains the detailed lesson plans used in this project. The lesson plans were written based on the objectives of the classes and the author's experience with seventh grade students. The lessons can be viewed as being grouped into four phases. The first two classes were designed for initial data collection and introduction to the project. Classes 3 through 13 introduced programming, design, and construction issues related to robot building as well as the development of the problem solving process. Classes 14 through 18 focused on design, programming, and problem solving issues related to the final project and the contest itself. Class 19 provided time for the post-test of problem solving skills using Form 8 of TABE-PS .

Approach

To test the validity of the study a combination of a descriptive/nonequivalent control group (Gay & Airasian, 2000) design was utilized. Two existing, heterogeneously grouped, Hilton Head Middle School seventh grade science classes participated in the study. Both groups were pre-tested using the TABE-PS Form 7 ©.

The TABE-PS was constructed to measure an examinee's ability to solve problems at levels acceptable for functioning in the workplace and society. It is a constructed response test that uses graphics and descriptions to help the examinee grasp the situation. South Carolina seventh grade students have some experience with graphic interpretation as these types of questions are used in the State's standardized assessment- the Palmetto Achievement Challenge Test (PACT). Before administering the pre-test using Form 7 of the TABE-PS student questions and concerns were addressed using the practice exercise provided.

Group 1 participated in a 19 period robot design class. Each class period consisted of 85 minutes of work time. Group 2 participated in the regular seventh grade science curriculum. At the end of the project, both groups were post-tested using an equivalent form of the TABE-PS (TBE-PS Form 8).

Before group 1 could begin learning the design and programming aspects of robot construction, they needed to learn that this type of job is best accomplished within groups. With this end in mind students were placed in groups of 4 or 5 students and spent one class period working on team building exercises that culminated in the design and production of a team logo that represented their group throughout the project. The next ten classes were devoted to instruction in ROBOLAB programming and mechanical engineering basics including the use of sensors and motors. These classes also involved a design component so that the students could be creative with their problem solving, engineering and programming skills. Near the end of the course, five of the classes focused on teams of students designing, constructing, and testing a robot that would participate in a drag race and showcase their programming skills.

Examining changes in problem solving skills within a classroom setting involves looking at complex issues. In order to gain a more complete understanding of the learning taking place within the project, we must recognize the complexity of the situation and attempt to delve into the many layers of interactions and situations occurring. A descriptive component examined problem solving throughout the duration of the study.

At the conclusion of each robot mission students completed journal entries designed to elicit responses based on the objectives of that class. The topics in the journals were based on the lesson objectives and investigator experience with seventh grade students. Some responses were objective and have correct or incorrect answers. Answer keys are provided for these entries. Some responses were subjective and are designed to gain insight into student reactions to activities and progress toward meeting the class objectives. The subjective answers are addressed in the descriptive analysis using the SIP (Appendix E). It was used to assess individual student performance within the technological problem-solving setting of the classroom. Observational field notes were kept to provide additional insight into the project.

The final project of the course was subdivided into two sections. Groups of students designed and programmed a robotic race car to compete in a classroom competition. Students were allowed to design the competition together. Their decision was to use individual time trials to decide on pairs of cars to drag race down a 15 foot drag strip created on the classroom floor. Because there were 5 groups participating they decided that the car with the fastest qualifying time bypassed the first race. After the initial time trials and between races teams were allowed to modify their car's programming and construction using available LEGO elements. Teams were allowed ten minutes to complete the modifications. Since improving problem solving skills was the focus of the project, modifications were allowed to see if students could learn from observing other groups' work. If they did, they might use the knowledge to improve upon their own work. This also gave the groups that constructed slower cars an opportunity to improve rather than to simply give up after the initial timed trials. This was intended to be a fun way for students to showcase their design, programming, and problem solving skills.

Resources

The author is a teacher a middle school that enrolls approximately 950 students in grades 6, 7, and 8. The school is located in Beaufort County; a rural southeastern South Carolina county. It is from this population that two existing seventh grade science classes were selected for participation in the project. The materials that were required for use in the project are LEGO Mindstorms for Schools to be used in building the autonomous robots, computers for programming the robots, a classroom in which the project was conducted, one copy of each form of the TABE-PS forms 7 and 8 for each student participating in the project. Two references were available for student use during all classes. These are *LEGO Mindstorms for Schools Using Robolab* (Cyr, 2002) and Building LEGO Robots for FIRST LEGO League (Hystad, 2002).

Reliability and Validity Issues

The TABE-PS was written for target populations in high school or post-secondary educational institutions. It was not written to assess basic reading, writing, or math skills. It was not written to assess basic content knowledge. It was written to assess basic problem solving strategies at a reading level consistent with average middle school expectations. Careful examination of the TABE-PS coupled with the researcher's years of experience with middle school students resulted in the determination that this testing instrument is appropriate for use with seventh grade students. Both classes selected for participation in this project were a heterogeneous mix of seventh grade students.

Chapter 4

Results

Introduction

All students began the robotics project with at least some experience in LEGO construction, in addition, no student entered with computer programming experience. Qualitative data were collected at various points during the project including

- group formation and early group interactions.
- introductory missions where students learned the basics of Robolab programming and the engineering concepts necessary for successful robot construction.
- the final project.

Quantitative data were gathered from the pre-and post-TABE-PS and were analyzed to detect changes in the students' problem solving skills.

Group Formation

Functioning as a group that must complete a task is difficult for middle school students. Most want to work with friends and do not visualize the benefits of working with a diverse group. As early as 1994, Stahl listed the following elements as necessary for successful cooperative learning activities: heterogeneous grouping, providing participating students with an equal opportunity for success and individual accountability. These same elements are important today and were used as a theoretical basis of group formation. The number of computers and LEGO equipment available dictated the formation of five groups of students.

Groups remained intact for the entire duration of the project and consisted of either four or five students. Informal conversations revealed that some students were hesitant to learn programming because of pre-conceived notions about the tedium involved. Students were asked to indicate a preference for building or programming to alleviate anxiety and to build self-confidence. Their input was taken into consideration during group formation. During the first two missions student jobs were assigned based on individual preference. During the last two missions student pairs (or triplets) switched jobs so that they could gain experience in both programming and construction. For the last mission, student groups decided among themselves which students were more expert at the two jobs and worked accordingly. Students were assigned individual identification numbers to protect their anonymity. Table 2 indicates student identification numbers, group assignments and initial jobs within the group. P indicates the students that served as the group's initial programmers and B indicates those serving as group's initial builders.

Table 2: Group Assignments

Student Identification Numbers and Assignments

Group				
1	2	3	4	5
2P	19 B	4P	7 P	18 B
10P	20 B	13 B	16 B	11P
17 B	9 P	8P	14 B	15 B
3B	6P	22B	12P	5P
1B			21P	23B

After receiving initial group assignments a class discussion was held to reinforce the idea that group success meant that every member of the group depended upon the other members. Social skills such as compromise, negotiation, and acceptance of constructive criticism were emphasized. At the conclusion of this discussion, students were given their first set of group tasks to complete. Each group had approximately 55 minutes to decide on a name for their group and to create a symbol that would represent their group throughout the project. At the end of that time, groups presented their team logos to the class and provided a written reflection on the group's working behaviors. Figures 1-5 include the group names, logos, logic behind group name selection, and field notes for the introductory group activity.

Name	The Isotones
Logo	Isotones
Meaning of Logo	The dictionary lists the definition of an isotone as "one of two or more atoms of different atomic number that contain the same number of neutrons." We also are different but parts of the same group.
Relevant Comments from Students	"I like being a builder because I feel like I can actually do it. When I don't know something someone else does. Then I learn it." "You have more opinions so you can check your answers. Not everything is done by you." "The worst thing about working in a group is if one person does not cooperate, then the whole team fails." "We don't always agree so you don't always get what you want."
Field Notes	Wanting to work with friends was important to this group. They spent a considerable amount of the allotted time disagreeing on a name for the group. Realizing that time was getting short one member of the group approached the researcher and asked for help in resolving the conflict. The disagreement revolved around the students' perceptions that the others wanted to be in charge. The researcher suggested randomly opening a scientific dictionary and looking for a word on the page that could somehow be used to represent the group. The name "Isotone" was chosen. All members of the group remained good natured about the disagreement and settled on the name relatively easily. There wasn't enough remaining time for the group to get creative beyond a quick Word Art image; however, they were satisfied with the agreement.

Figure 1: Group 1 Team Building

Name	SPIKE
Logo	
Meaning of Logo	An acronym for "Smart People Invent Kool Experiments"
Relevant Comments from Students	"The best thing about working on a team is that you're not in it alone." "You get to meet new people." "The worst thing about working in a group is that you don't get to be with your friends."
Field Notes	Although this group expressed a preference for working with friends in writing they never verbalized the wish and worked well together. They easily came to agreement on the logo and accepted each other's suggestions with grace. This group worked efficiently and was the first to finish the task. They were proud of their work and willing to share it with others.

Figure 2: Group 2 Team Building

Name	MJ2K
Logo	
Meaning of Logo	Students used their first initials to generate their logo. 2K refers to the two students in the group with the first initial of K.
Relevant Comments from Students	"The best thing about working in a group is that you don't have to do everything." "You get to work with different people and get to see what kind of ideas they have that are good." "The worst thing about working in a group is that everyone has to agree on the same idea. They don't always do that."
Field Notes	This group immediately came together and worked to a common goal. They easily completed the task within the allotted amount of time. The comment about working with different people was especially insightful. The researcher asked the group if they were aware of the name of NASA's 2004 Mars Mission. They responded that they did not. Its name is M2K4.

Figure 3: Group 3 Team Building

Name	R Unit
Logo	
Meaning of Logo	The logo is meant to represent the unity of the group.
Relevant Comments from Students	"The best thing about working in a group is that it is less work and lots of fun." "You have people to depend on and you don't have to do everything by yourself." The worst thing about working in a group is that you might not all agree" "If there are people that don't help, they are a disadvantage to the group."
Field Notes	As indicated in the writing the element of fun is important to this group. It's also obvious in their behavior They required several reminders to complete the task at hand. They are a good natured group and will work well together if they can harness the desire to have fun and channel it into their work.

Figure 4: Group 4 Team Building

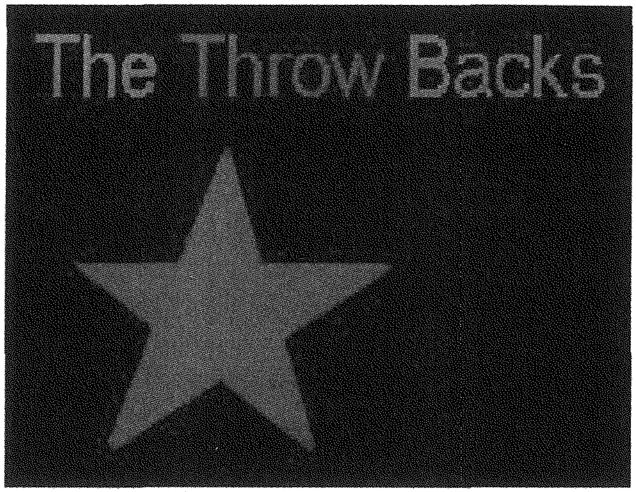
Name	The Throwbacks
Logo	
Meaning of Logo	The five points on the star represent the five people in the group.
Relevant Comments from Students	"The best thing about working in a group is that you don't have to do all the work." "Stuff gets done faster." The worst thing is that "I don't like my group and the arguing".
Field Notes	This group expressed strong dislike for the other group members. The researcher requested that they give each other a chance to contribute to the group. Student #18 continued to be especially uncooperative and refused to work with the group. This exacerbated their problems; however, student #23 took a leadership role and rallied the others to complete the task. It is interesting to note that student #23 is learning disabled and does not usually take leadership responsibilities.

Figure 5: Group 5 Team Building

Introductory Missions

During this phase of the project students learned to construct robots using the LEGO bricks and to write and download computer programs using Robolab. The missions were based on LEGO Mindstorms for Schools Starter Set. Groups worked on each mission for two class periods and rotated through a total of five projects. Each project began with a simple program and progressed to more difficult ones. When groups finished early they modified the robot and wrote their own programs. Two of the available projects were more open ended for those groups that liked a challenge. The missions included: My House, Torbot (a tractor like robot), The Car, and The Gadget. The open ended challenging missions were called The Mutated Bug and Human Habitat Challenge.

Journal Entry 2 was collected at the end of the first class and served to provide a basic idea of the students' understanding of the use of the RCX brick and understanding a simple program. Students completed journal entries at the end of the first class as well as at the end of each mission completed. Table 3 summarizes the number of the Journal Entry 2 items students answered correctly and incorrectly. Examination of the items missed column indicates that student misconceptions were grouped in two areas. Frequently they misunderstood how to re-write the program and were not familiar with the parts of the RCX brick. In particular they could not differentiate between the input and output ports of the brick. It was important to clear these misunderstandings so that the work could progress so they were addressed at the beginning of the next class.

Table 3: Grading Summary of Journal Entry 2

Student	Number Correct (total=9)	Item Missed
1	7	2, 3
2	7	2, 3
3	7	2, 3
4	9	none
5	7	4a, 4b
6	9	none
7	6	4a, 4b, 4f
8	9	none
9	9	none
10	7	2, 3
11	7	4a, 4b
12	6	4a, 4b, 4f
13	9	none
14	6	4a, 4b, 4f
15	6	4c, 4d, 4e
16	6	4a, 4b, 4f
17	7	2, 3
18	4	4a, 4b, 4c, 4d, 4e
19	6	4a, 4b, 4f
20	9	none

21	6	4a, 4b, 4f
22	8	4e
23	7	4a, 4b

Training Missions

The purpose of these training missions was to teach students the basics of computer programming using LEGO Robolab and to explore the uses of touch sensors, light sensors, gears, pulleys, and motors. Students constructed five robots from a selection of six available. On the first day of the training missions a researcher conducted a discussion that detailed each mission.

Groups were provided with a selection of robot construction kits from which to choose. They worked on a mission for two class periods. During each mission they were directed to begin by constructing and programming a robot according to provided plans. Each plan illustrated specific concepts about the hardware and software. After becoming familiar with the workings of the materials students were directed to re-design the robot and re-write a program. The Robolab program has the capability of producing programs that have a maximum of fifteen hundred steps so there was a high degree of challenge inherent in the projects. Table 4 provides information about the programming and construction processes occurring and was gathered from the student journals during missions one, three, and five.

Table 4: Introductory Missions One, Three, and Five

Mission 1: Isotones (Students 1, 2, 3, 10, & 17)

This group selected to construct a tractor type robot. The robot utilized two motors and demonstrated the use of a touch sensor. Students were able to follow construction and programming instructions well and were able to get the robot to perform the required actions. They have a basic understanding of how each step in the program affects a segment of the robot's behavior. The group's has not yet developed the ability to write even a simple program and did no substantial modifications to the design of the robot. The group was successful at overcoming individual differences and students indicated satisfaction with their role within the group.

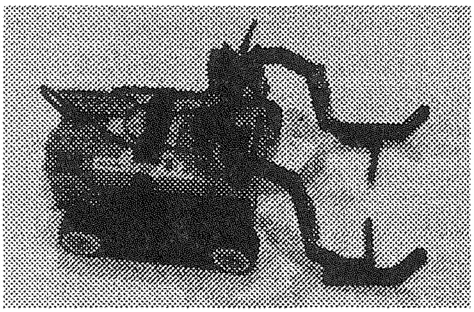


Photo is representative of tractor robots created by all groups throughout the project.

Mission 1: SPIKE (Students 6, 9, 19, & 20)

This group selected to construct the human habitat challenge project. The project involved learning to use a motor, a light, a touch sensor, and a piano. It was more open ended than the "My House" robot in that students had a different selection of pieces from which they constructed the robots. They attempted to design an operational fan, a stereo that played music, a light that turned on automatically, and a doorbell. They were a good natured group and wanted to try their hands at a challenge. They were successful in creating the operational fan and automatically turning on the light, however, programming the touch sensor to ring a doorbell proved to be problematical. The group was able to download simple songs to the RCX; however, they did not place the song within the program. Initially three of the four students expressed a wish to be the programmers. One was gracious about switching jobs in so that one teammate was not alone with the construction tasks.

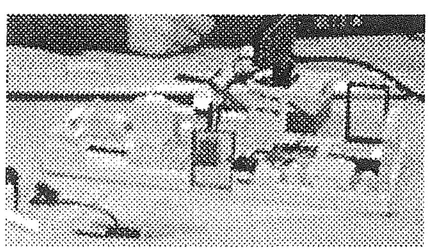


Photo is representative of Human Habitat robots created by groups throughout the project.

Mission 1: MJ2K (Students 4, 8, 13, & 22)

This high energy group selected to construct and program the car. They immediately paired into partners that preferred to build and program. Although they all wanted to be an expert in their chosen fields, they were cooperative in helping each other as well as other groups. Following the construction plans was not a problem and although the programmers were not familiar with Robolab they approached it with a great sense of adventure and were very exploratory of the program's abilities. This mission utilized one motor to construct a vehicle that was propelled by a simple pulley and used a touch sensor. They were quick to complete the mission as described in the instructions and progressed into modifying the robot and program. During the first mission they were successful in creating a program that included a fork, a programming method that allowed the robot to conduct two tasks simultaneously.

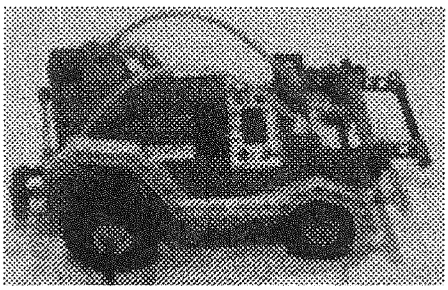


Photo is representative of the car robots created by groups throughout the project.

Mission 1: R Unit (Student 7, 12, 14, 16, & 21)

This highly social group selected to construct the "My House" robot. Their immature approach to their work resulted in work that did not meet the requirements and was incomplete. Rather than cooperate with each other they continued to place blame on their teammates without seeing the weakness of their own contributions. Encouragement and suggestions offered by the researcher and classmates from outside the group did not improve their performance. Toward the end of the mission the programmers gained interest in learning to program the house to play music, however, there was too little time left for them to be successful.

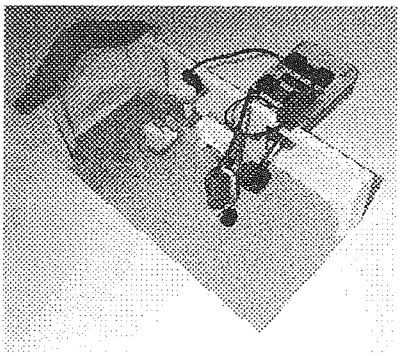


Photo is representative of "My House" robots created by groups throughout the project.

Mission 1: The Throwbacks (Student 5, 11, 15, 18, & 23)

This group began the mission feeling disgruntled with the people they were to work with. Student 18 refused to engage in the tasks and this further strained relationships among group members. Students 5 & 15 were interested only in play so students 11 & 23 struggled to complete the work. Student 23 began to take charge of the work and was interested in both programming and building. This person worked hard to complete the job but the lack of cooperation among group members was too much of a hindrance and the job could not be completed by one person. Frustration was evident; however, it was overcome because her interest and determination overrode the frustration.

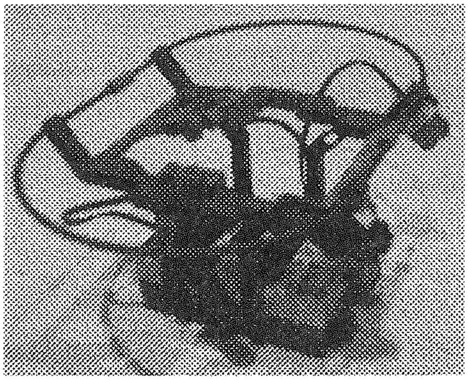


Photo is representative of "Gadget" robots created by groups throughout the project.

Mission 3: Isotones (Students 1, 2, 3, 10, & 17)

The selected mission is the human habitat. Students wanted the robot to move a piece of furniture using a motor, to use a light sensor to turn on a lamp, and for the home to play music. They indicated that they preferred their original jobs within the group. The program was operational; however, it did not perform as the students expected. Troubleshooting skills were not very efficient. Students were easily frustrated and not particularly interested in correcting the programming problems. Rather than search for solutions they were willing to accept that the program did not work.

Mission 3: SPIKE (Students 6, 9, 19, & 20)

All group members shifted their work assignments well. They decided to construct the robotic bug and helped each other when they found a difficulty with their work. Students 19 and 20 have really blossomed. Student 20 became the construction expert of the group. Student 19 became interested in programming a robot that had the capability of using a light sensor to follow a line. Because it was a project that was different from the current mission she arranged to complete work independently for another class so that she could use the time to work on the extra project.

Mission 3: MJ2K (Students 4, 8, 13, & 22)

They elected to construct the gadget. Completion was easy and there was ample time to look for challenges. They decided to attempt to construct a catapult and completed a working model with little difficulty. Students in this group now indicate a preference for construction although the original programmers continue to do so for their group.

Student 4 became the class programming expert and other groups are now approaching him for troubleshooting help.

Mission 3: R Unit (Student 7, 12, 14, 16, & 21)

Students continue their silly approach to their work. It's unfortunate that none of the group is emerging as a leader so they all continue to flounder and were unable to complete their mission constructing the tractor. Student 12 expressed a strong dislike for working with the LEGO bricks, student 16 expressed feelings of inadequacy when working with computers, student 21 did not see that there was any creativity allowed in programming, and to her it was merely a matter of changing what already existed. Only student 7 expressed the thought that programming was an exercise in thought and took time to master.

Mission 3: The Throwbacks (Student 5, 11, 15, 18, & 23)

Although this group continues to struggle because of their strong dislike for their team members, student 23 has emerged as the clear leader. She has overcome the frustration of working with uncooperative partners her ability to focus on her work is pulling the group through. In the construction of the house project she eagerly took on the roll of both programmer and builder. Previously this student has had to struggle to be successful academically. Clearly she is proud of the progress she has made thus far during the project.

Mission 5: Isotones (Students 1, 2, 3, 10, & 17)

The group continues to be good natured and although they help each other when needed the preferences for jobs has not changed. Those who began with an interest in programming continued to prefer that job as did those with a building interest. Student #2 did develop an additional interest in construction and began to show interest in constructing the robot that could follow the line. He also arranged to complete some coursework independently so that he could spend extra time working on the robotics project. This interest led him to form a working relationship with student #19. Although they were from different work groups they easily formed a partnership to pursue their common interest.

Mission 5: SPIKE (Students 6, 9, 19, & 20)

This group continued to move seamlessly between programming and construction. Student #20 emerged as a class construction expert lending his help to other groups in the class. Their cooperative efforts paid off as they were able to complete the mission easily.

Mission 5: MJ2K (Students 4, 8, 13, & 22)

The group's excellent work ethic continues to serve them well. Once again they easily finished their work and quickly busy themselves looking for challenging ways to adapt the robot. Their approach to learning has been to improve on or change the mechanical aspects of the robot. Programming improvement has been limited to the minimum necessary to fit the mechanical needs of the robot. During this mission the group began to experiment with using two gear trains to increase the power of vehicles.

Mission 5: R Unit (Student 7, 12, 14, 16, & 21)

Student 21 continues to take on the leadership role of her group. Students 5 & 8 are beginning to take some initiative at working with her. They became involved more with the construction aspects of the project while she specialized more in the programming aspects. Student 18 continues to resist involvement despite the best efforts of the classmates

Mission 5: The Throwbacks (Student 5, 11, 15, 18, & 23)

Unfortunately, this group has not been able to overcome the difficulties they have with working with each other. Student 23 is thoroughly immersed in the project; however, her group members are either uninterested or overly social.

In general, students are beginning to show boredom with the routine of the class. Although they have made some improvements in their programming skills they are still rudimentary. Students were over-confident in their programming abilities and did not take the initiative to delve further into the activities.

Final Project: The Dragster

Early in the "Mission" stage of the project it became apparent that there was a higher learning curve for learning to program Robolab than anticipated. Therefore a decision was made to incorporate student input into the design of the final project. Both male and female students expressed a desire to design, construct and program dragsters and to conduct a drag race. Given the high interest in mechanical manipulation of the bricks and limits of the student's programming abilities, it is not surprising that this type of final project appealed to the students. It required a limited amount of programming and offered a large degree of freedom in designing the car to travel in a straight line. The researcher placed the following constraints of each vehicle:

- Groups had three class periods to design, construct, and experiment with their group's final vehicle. A fourth period was allotted to conduct the races.
- Cars could use no more than four wheels. An assortment of wheels and tractor treads was provided. Students were allowed to change tires throughout the project.
- Cars could use no more than two-9 volt motors with gear reduction.
- One light and touch sensor could be used if teams desired.
- Each group received a construction kit of identical LEGO bricks.
- Additional LEGO elements were available to all groups for use as they desired.
- Groups designing vehicles aimed as destroying other vehicles were not allowed and would be disqualified. A spirit of friendly competition was emphasized.

Students set up a 15 foot, two lane drag strip on the classroom floor. The two lanes were divided by a piece of electrical tape. Available room within the classroom dictated the length of the drag strip. As a whole, the group decided to conduct individual time trials for each vehicle. These time trials were then used to match cars against one another for the initial race. Given that there were five participating vehicles the class agreed that the car with the fastest time would earn a pass on the initial race. At the end of the time trials and between each race, groups were provided 10 minutes to repair, re-design, and re-program their vehicles. This was done in order to keep student interest and to allow them to learn from a car's past performance and improve upon it. Table 5 indicates the individual time trials of each of the five vehicles entered into the competition. Figure 6 indicates the paired races and the winners of each race.

Table 5: Time Trials

Group	Time (seconds)
1: Isotones	5.1
2: Spike	5.3
3. MJ2K	3.9
4. R Unit	7.9
5. The Throwbacks	9.0

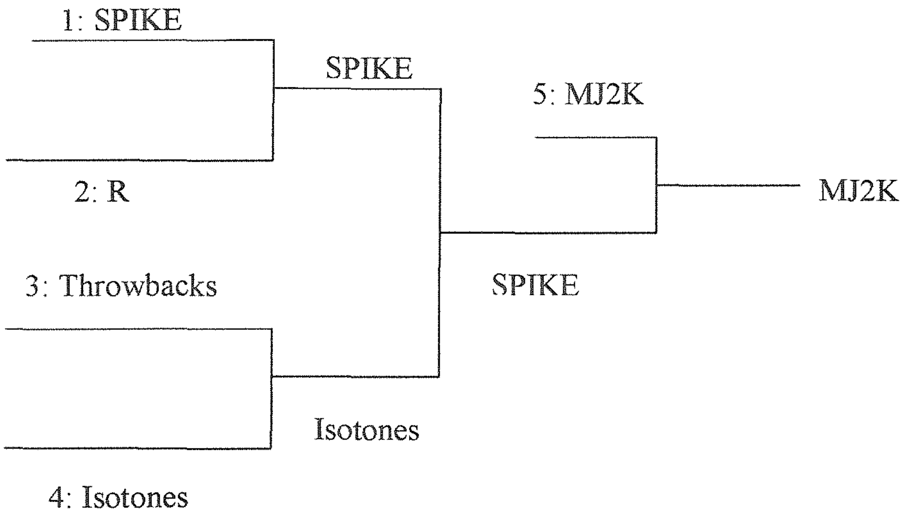


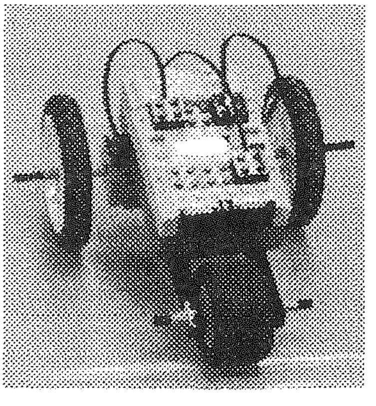
Figure 6: Drag Races

Table 6 includes researcher notes on specific details of the final product produced by each group as well as a photo of the final vehicle constructed by the group.

Table 6: Final Project

Isotones

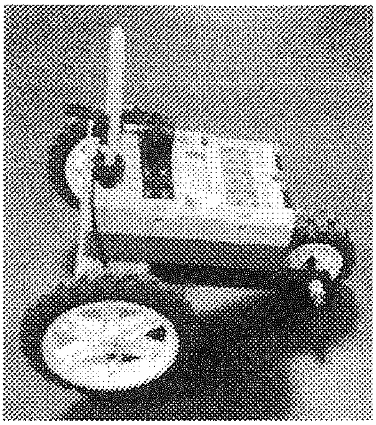
Students 2 & 10 continued to function as the group's programmers. Evidence of student 2's interest in programming can be seen in the photo of their final entry. A light sensor is connected to input port 1 (near the front of the vehicle). During any free moments this student continued to work on programming the car to track along a black line. Students 1, 3, & 17 constructed and troubleshot the vehicle. They spent considerable time trying various wheels in an effort to gain speed. They also experimented with weight as it would affect traction and speed. In addition, considerable time was invested in fine tuning the vehicle to make it go as straight as possible. After the first race the group decided not to modify the robot for future races. This robot is rather fragile as the students did not make use of any type of frame to help add sturdiness to the vehicle.



Isotone's Final Project

SPIKE

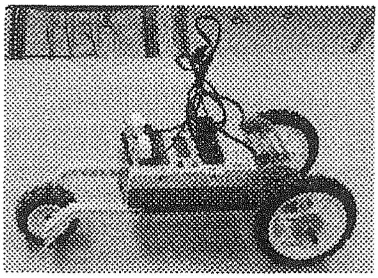
For this project student 20 emerged as the leader. Students 9 & 6 served as troubleshooters who spent a large amount of time balancing the wheels so that the robot would run straight. They also discovered that the motors ran at slightly different speeds. That contributed to the car having difficulties staying on a straight course. They solved the motor problem by stacking the leads to run off the same motor and were satisfied with the results. The group fine tuned the mechanics of the robot between races.



SPIKE's Final Project

MJ2K

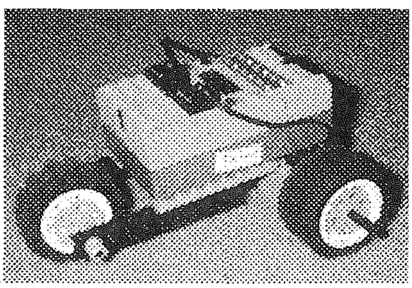
This group blossomed during this project. They thrived on the open-endedness and worked well to design and construct the car. Students 4 & 8 still served as the programmers although their interest in design was evident. Student 13 became the class expert on automotive design and went so far as to run test trials using water on the tires in an attempt to reduce friction. Although this is another 3-wheeled design there were several elements added to their project. Working headlights added a touch of realism. They were the only group to add a gear train to the rear wheels. Although they had no formal training in the effects of gear reduction they did have an intuitive sense that this would make the car run faster. The larger gear can be seen at the left of the rear tire. Even when other teams saw the effects of the gear train on the speed of this vehicle none of them made any attempt to modify their own car to include this feature. MJ2K's car easily won the drag race finals. When the teammate reached to start the program and missed the run button at the beginning of the race the competitor's car got off to a healthy lead. This vehicle had no trouble overtaking the leader and bolted to the finish line. The team received a well deserved round of applause from their classmates.



MJ2K's Final Project

R Unit

This robot was extremely fragile. Close examination of the undercarriage shows that two LEGO pieces were simply snapped together. The weight and motion of the car caused the pieces to break apart. Although they were good natured about the shortcomings of their robot they showed very little interest in improving its performance.



R-Unit's Final Project

Student Individualized Performance Inventory (SIP)

Teachers implementing problem solving activities into their classrooms need reliable assessment tools. The SIP allows teachers to evaluate individual performance in technological problem solving group activities. Scoring consists of assigning a numerical value based on a five point scale (5 expert: 1 novice) for each of the twelve strands of the SIP. A single score is computed for each dimension by averaging the scores of the three strands of each dimension. Custer, Valesey, & Burke (2001) suggest calculating an overall mean score by averaging the four dimension scores.

Students were scored using the SIP at the end of their first mission and again at the end of the final project but before the time trials for the race. Field notes, standings in the time trials, and the SIP results were examined to see if any patterns emerged. Table 7 details the individual student SIP scores and Table 8 compares the time trial standings of the groups to the group's mean SIP score.

Although the sample is small, the SIP scores indicate that individual scores within the group were reflected in the performance of the technology designed. During the time trials the cars designed by groups one and two earned similar times and indeed these group's SIP scores were very similar. It appears that the willingness of group two to continually modify their car paid off when their car performed faster than the car of group one and won their race.

Examination of the sub-scores of each dimension indicates that there are areas of student weakness within the various strands. One area of weakness is the lack of documentation of technical activities. It was not uncommon for students to leave the documentation to the end of the class period and then to run out of time without completing the requested documentation. The second area of weakness was the resistance of students to consulting reference materials. Students had reference manuals for each mission they completed, a Robolab reference manual, and a LEGO encyclopedia available as aids. Through the entire duration of the project it was necessary for the researcher to physically show them where to find helpful material. Independently consulting the reference material was a skill that did not develop during of this project.

Table 7: SIP Scores

Group	Student	Dimension (Beginning) 1	2	3	4	Mean (Beginning)	Dimension (End) 1	2	3	4	Mean (End)
1	1	1.67	1.67	1.33	2.00	1.67	2.33	2.33	3.00	2.33	2.50
	2	2.00	2.00	2.33	2 .00	2.08	2.67	2.67	3.00	2.67	2.75
	3	1.67	1.67	1.33	2 .00	1.67	2.33	2.33	3.00	2.33	2.50
	10	1.67	1.67	2.33	2.00	1.92	2.33	2.33	3.00	2.33	2.50
	17	1.67	1.67	1.33	2 .00	1.67	2.33	2.33	3.00	2.33	2.50
2	6	2.00	1.67	1.67	2.00	1.84	2.67	3.00	4.00	3.00	3.17
	9	2.00	1.67	1.67	2.00	1.84	2.67	3.00	4.00	3.00	3.17
	19	1.33	1.67	1.67	2.00	1.67	2.67	3.00	4.00	3.00	3.17
	20	1.67	1.67	1.67	2.00	1.84	2.67	3.00	4.00	3.00	3.17
3	4	3.67	2.67	3.00	2.33	2.58	3.67	3.67	4.33	3.33	3.75
	8	2.33	2.67	3.00	2.33	2.58	3.67	3.67	4.33	3.33	3.75
	13	1.67	2.00	3.00	2.33	2.25	3.33	3.33	4.33	3.33	3.58

	22	1.67	2.00	3.00	2.33	2.25	2.33	2.33	3.67	2.33	2.67
4	7	1.33	1.00	1.33	1.00	1.17	1.67	1.67	2.67	1.67	1.92
	12	1.33	1.00	1.33	1.00	1.17	1.67	1.67	2.67	1.67	1.92
	14	1.33	1.00	1.33	1.00	1.17	1.67	1.67	2.67	1.67	1.92
	16	1.33	1.00	1.33	1.00	1.17	1.67	1.67	2.67	1.67	2.17
	21	1.67	1.00	1.33	1.33	1.33	2.00	1.67	3.00	2.00	2.17
5	5	1.33	1.00	1.33	1.00	1.17	1.67	1.33	2.67	1.67	1.84
	11	1.33	1.00	1.33	1.00	1.17	1.67	1.33	2.67	1.67	1.84
	15	1.33	1.00	1.33	1.00	1.17	2.00	1.67	3.00	1.67	2.09
	18	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	23 (withdraw)										

Table 8: Race Standings Compared to Mean SIP Score

Group	Standings	Mean SIP
3: MJ2K	1	3.44
2: SPIKE	2	3.17
1: Isotones	3	3.18
4: R Unit	4	1.97
5: The Throwbacks	5	1.69

Statistical Analysis

To determine whether the pre-test means of the control and experimental groups were statistically different a *t*-test for independent samples was conducted. The test resulted in a *t* of -1.118 and a p value of .24. This is significantly higher than 5%; therefore, there is no evidence that the mean levels of the two groups were significantly different at the beginning of the study. Table 9 summarizes the results of this *t*-test.

Table 9: *T*-test of Pre-test Scores

Sample	
control	19
experimental	21
Mean	
control	14.9474
experimental	17.1905
Standard deviation	
control	5.22253

experimental	6.68296
Standard error of the mean	
control	1.19813
experimental	1.45834
t	-1.118
p	0.24

To determine whether there is a significant difference between the pre- and post test scores of the control and experimental groups a second *t*-test was conducted. Test results indicate that although the general trend was that the experimental group scored higher on the overall test of problem solving abilities the difference was not significant. Table 10 summarizes the data from this *t*-test.

Table 10: *T*-test of Pre- and Post-test Differences in Problem Solving Abilities

Sample	
control	19
experimental	21
Mean of differences	
control	1.68421
experimental	2.80952
Standard deviation of differences	
control	4.15067
experimental	4.00773
Standard error of the mean of differences	

control	0.952229
experimental	0.874559
t	0.8704
p	0.19

The TABE-PS provides data on four areas of problem solving competencies. The third *t*-test compared the differences in the pre- and post-test scores of the student's competency in employing reading and math skills to identify and define a problem. The test resulted in a *t* of -0.4715 and a p value of .68. This is significantly higher than 5%; therefore, there is no evidence that the students' abilities to use reading and math skills to identify and define a problem two groups were significantly different. Table 11 summarizes the differences in the pre- and post-test scores of Competency 1 of the TABE-PS.

Table 11: *T*-test of Differences of Pre-and Post-Test Scores of TABE-PS Competency 1

Sample	
control	19
experimental	21
Mean of differences	
control	-0.157895
experimental	-0.333333
Standard deviation of differences	
control	1.30227
experimental	0.221825

Standard error of the mean of differences	
control	0.298761
experimental	0.221825
t	-0.4715
p	0.68

The fourth *t*-test compared the differences in the pre- and post-test scores of the student's competency in examining situations using problem-solving techniques. The test resulted in a *t* of -0.1184 and a *p* value of 0.55. This is significantly higher than 5%; therefore, there is no evidence that the students' abilities to examine situations using problem-solving techniques were significantly different. Table 12 summarizes the differences in the pre- and post-test scores of Competency 2 of the TABE-PS.

Table 12: *T*-test of Differences of Pre-and Post-Test Scores of TABE-PS Competency 2

Sample	
control	19
experimental	21
Mean of differences	
control	2.05263
experimental	1.95238
Standard deviation of differences	
control	2.67652

experimental	2.6735
Standard error of the mean of differences	
control	0.614035
experimental	0.583406
t	-0.1184
p	0.55

The fifth *t*-test compared the differences in the pre- and post-test scores of the student's competency in making decisions about possible solutions to a problem. The test resulted in a *t* of 0.5838 and a *p* value of 0.28. This is significantly higher than 5%, therefore, there is no evidence that the students' abilities to make decisions about the possible solutions to a problem were significantly different. Table 13 summarizes the differences in the pre-and post-test scores of Competency 3 of the TABE-PS.

Table 13: Differences in the Pre- and Post-test Scores of TABE-PS Competency 3

Sample	
control	19
experimental	21
Mean of differences	
control	0.684211
experimental	1.09524
Standard deviation of differences	
control	2.10957
experimental	2034318

Standard error of the mean of differences	
control	0.483969
experimental	0.511323
t	0.5838
p	0.28

The sixth *t*-test compared the differences in the pre- and post-test scores of the student's competency in evaluating outcomes, and effects of implementing solutions. The test resulted in a *t* of 2.374 and a *p* value of 0.011. This is lower than 5%; therefore, there is evidence that the experimental group was significantly more competent in the ability of to evaluate outcomes and effects of implementing solutions. This indicates that the group that participated in the Robolab project was significantly better able to extend meaning and restructure information, integrate solutions into existing systems, demonstrate learning from a problem-solving situation, and suggest possible next steps. Table 14 summarizes the differences in the pre-and post-test scores of Competency 4 of the TABE-PS.

Table 14: Differences in Pre- and Post-test Scores of TABE-PS Competency 4

Sample	
control	19
experimental	21
Mean of differences	
control	-0.894737
experimental	0.0952381

Standard deviation of differences	
control	1.14962
experimental	1.48003
Standard error of the mean of differences	
control	0.263742
experimental	0.322968
t	2.374
p	0.011

Summary

Twenty-three students were placed in five problem-solving and design groups. As a group these students worked together through team building, introductory missions, and a final design challenge. It is encouraging that the experimental group performed significantly better than their control counterparts in their abilities to evaluate the outcomes and effects of implementing solutions. They could better extend meaning, restructure information, integrate solutions into existing systems, demonstrate learning from problem-solving situations, and suggest possible next steps. Some students knew their work preference from the beginning and continued to prefer either programming or construction and honed these skills throughout the project. Other students discovered that they enjoyed activities that they previously thought they would dislike. Of these, several became experts in their newly discovered talents. The project provided students with new opportunities to exhibit leadership skills. It is refreshing to see students surprise themselves and emerge as effective group leaders while enjoying the learning process.

Chapter 5

Conclusions, Implications, Recommendations, and Summary

Introduction

Teachers are expected to deliver lessons that move their students toward mastery of subject specific content standards, technology standards, and work place skills. SC teachers, like teachers across the nation, work toward these goals. There are few concrete models that offer direction in creating and presenting lessons that integrate math, science, technology, and problem solving skills. This dissertation modeled one way to accomplish this and examined four questions:

- Which technology and state science and math standards could be integrated into a programmable LEGO project for middle school students?
- Which technology-intensive workplace skills could be developed within the project efforts and how could their mastery be measured?
- How can problem-solving skills including analysis and design be incorporated into the project?
- How do students' problem-solving skills change as a result of participation in the project?

The discussion that ensues analyzes the data as it relates to the research questions and draw conclusions from it. Both the benefits and limitations of the study have direct affect on the practical applications and usefulness of the study and are included in the discussion. Suggestions for future research are offered so that as an academic community we can continue to design opportunities that strengthen and enrich the educational experiences of all of our students.

Conclusions

Which technology and state science and math standards could be integrated into a programmable LEGO project for middle school students?

A close examination of the ISTE technology standards and the SC 7th grade math and science standards indicated that it is important to improve the problem solving skills of middle school students. For this reason applicable standards and competencies are listed in Appendix B (science standards), Appendix C (math standards), and Appendix D (ISTE Technology Standards).

SC standards place a high value on inquiry skills. These skills focus on the abilities necessary to do scientific inquiries and include observing, classifying, selecting appropriate tools, inferring, predicting, summarizing, analyzing, and predicting. Problem solving skills are included among the inquiry skills.

Although many of the science inquiry skills were integrated into this study the grade level science content standards did not lend themselves to integration. As in science, math process skills and ISTE Technology Standards including problem-solving skills were easily integrated. Unlike science content standards, some algebra and measurement content standards were integrated into the study. SC has adopted the ISTE Technology Standards; however, they are not measured using the standardized test that students are required to take.

Teachers often struggle to complete presentation of all the required course standards in the allotted amount of time. Because of this an integrated science-problem solving course would be better suited as an enrichment class or as part of an after school or summer camp program.

Which technology-intensive workplace skills could be developed within the project efforts and how could their mastery be measured?

The Secretary of Labor's SCANS Competencies in Management and Use that were integrated into this program are listed in Appendix E. The SCANS Competencies were integrated into the design of the project and were treated the same way as were science, math, and technology standards. Groups of students were required to demonstrate these competencies in their work. Journaling, cooperative group work, and technology usage were required in order to successfully complete a functioning robot. Evaluation of skill levels was both descriptive and quantitative. The TABE-PS required students to examine resource allotment, interpret and convert information, and understand system connections. Specific conclusions gathered from the TABE-PS are discussed with research question four.

How can problem-solving skills including analysis and design be incorporated into the project?

Polya's classic four-step problem solving method was introduced via a traditional lecture/discussion (Appendix I). Immediately following this discussion students completed a brief journal entry where they demonstrated the ability to recognize a problem, devise a plan to solve the problem and test the feasibility of their plan by acting out an algorithm of the robot's response to their plan. Students could adequately state an appropriate problem and could devise a plan from which they could begin to solve the problem; however, they had difficulty seeing beyond the word "algorithm". Despite efforts to simplify the meaning by demonstrating what was required was to think (or walk) through the steps they expected the robot to perform they continued to have difficulties in this area. In future iterations of the course, it is suggested that the word "algorithm" be omitted from the discussion.

An analysis and design project where groups of students constructed dragsters served as a culminating activity. The SIP (Appendix F) served as the rubric whereby individual students were independently evaluated on their contributions to the project. This rubric ranks performance on a scale of beginner (1) to expert (5) and evaluates four dimensions of problem solving including:

- Problem Design & Clarification
- Develop a Design
- Model/Prototype
- Evaluate the Design Solution.

SIP scores indicate that teams of students constructing higher performing vehicles tended to score higher on the rubric. Two noticeable areas of student weakness emerged from this data. Student documentation and research skills were weak. They tended to get caught up in the manipulation of the LEGO bricks rather than to document their progress in their written journal entries. It was not uncommon for the groups to simply run out of time before the documentation was complete. Research skills were another area of student weakness. Despite the availability of several resources students were resistant to help themselves out of difficult situations by referencing the research materials. Students resisted encouraging reminders to utilize the resources and continued using trial and error to fix problems encountered. This was not serious for mechanical difficulties but proved to be inefficient and time consuming with programming difficulties. Overall the results were uncomplicated, unimaginative programs and incomplete documentation.

How do students' problem-solving skills change as a result of participation in the project?

The TABE-PS was selected as the problem solving measurement instrument because of its ability to provide overall problem solving data as well as data from four sub-tests of problem solving abilities including:

- Employs reading and math skills to identify and define a problem.
- Examines situations using problem-solving techniques.
- Makes decisions about possible solutions.
- Evaluates outcomes and effects of implementing solutions.

Analysis of the *t*-tests for independent samples showed that the experimental and control groups were not statistically different at the beginning of the research. A *t*-test comparing the differences of pre- and post-test scores indicated that the experimental group performed better than the control group although the difference was not significant. *T*-tests comparing the sub-scores indicated that there was no significant difference between the control and experimental groups in their abilities to employ reading and math skills to identify and define a problem, to examine situations using problem-solving techniques, or to make decisions about possible solutions to a problem. However, the experimental group did perform significantly better in its ability to evaluate outcomes and effects of implementing solutions. This indicates that the experimental group was better able to extend meaning and restructure information, integrate solutions into existing systems, demonstrate learning from a problem-solving situation, and suggest possible next steps.

Implications

The results of this study are limited to English speaking students in a mid-sized rural school district. It provides one model which middle school teachers may use to offer students practice in improving their problem solving skills. The LEGO bricks are high interest manipulatives that can be used as a basis from which programming skills can be taught in a non-threatening environment. The limited complexity and variety of student created programs implies that they require more programming instruction if they are to gain full use of all the capabilities of the program. Student difficulties with solving mechanical engineering problems stemmed from their reluctance to consult resources. Brief lessons in topics like gear trains or structural strengthening could provide them with the knowledge needed to create improved robots.

Recommendations

Research aimed at improving student problem solving skills should continue. This study investigating the problem solving skills of middle school students was exploratory and therefore much of the data collected were descriptive. Future research efforts should increase their focus on the quantitative collection of data. Students who participated in the Robolab project were significantly better at evaluating the outcomes and effects of implementing solutions than were their peers who did not participate in the project, therefore the course design should refined and improved. One way to accomplish this would be to offer a robotics design course for a longer period of time. This would be easier to implement in an after-school or summer camp program.

Learning to program was more time intensive than anticipated and the physical manipulation of the LEGO bricks proved to be a strong attraction to students. Because it was difficult for students to stop playing with the bricks long enough to learn to write the computer programs, future courses should offer more initial class time when students are provided with pre-constructed robots and spend additional time focusing on learning to write programs. Once students have a substantial background in writing their own programs the design phase of the project should be implemented.

There is an additional need for the development of assessment tools specific to middle school students. The TABE-PS was normed for use with high school students. A trial using the practice pre-test with non-participating students indicated that the TABE-PS was suitable for use with seventh grade students. If national and state standards continue to require teachers to provide students with opportunities to improve their problem solving skills appropriate assessment tools should be developed to measure their progress.

Summary

This research provides one model that teachers may use to build the programming, problem solving, and design skills of middle school students. Using the LEGO Robolab robot invention system students learn to design, program, and troubleshoot robots that perform autonomously. This research employed a combination descriptive analysis of student reactions to the activities and a pre-test/post-test analysis of problem solving skills. The robotics course was divided into three parts. During the initial classes students familiarized themselves with writing programs and construction of the robots. After completion of this initial stage of the course student groups completed a series of five missions where they learned to integrate motors, light and touch sensors into their robots. During the final stage of the course students worked together with their groups to design, construct, and program a vehicle that competed in a drag race.

The information gathered from the TABE-PS showed a general trend for improved problem solving skills. Two existing seventh grade science groups participated in the study. One group served as the control group. They were pre-tested using the TABE-PS, participated in the general seventh grade science curriculum and were post-tested using an alternative form of the same testing instrument. The experimental group was pre-tested, participated in the robotics project, and were post-tested using the alternative form of the TABE-PS.

Pre and post-test scores of the two groups of students were analyzed using a *t*-test for independent samples. It indicated that the experimental group did not perform significantly better than the control group. *T*-tests comparing the sub-scores indicated that the experimental group performed significantly better in its ability to evaluate outcomes and effects of implementing solutions including the ability to extend meaning and restructure information, integrate solutions into existing systems, demonstrate learning from a problem-solving situation, and suggest possible next steps.

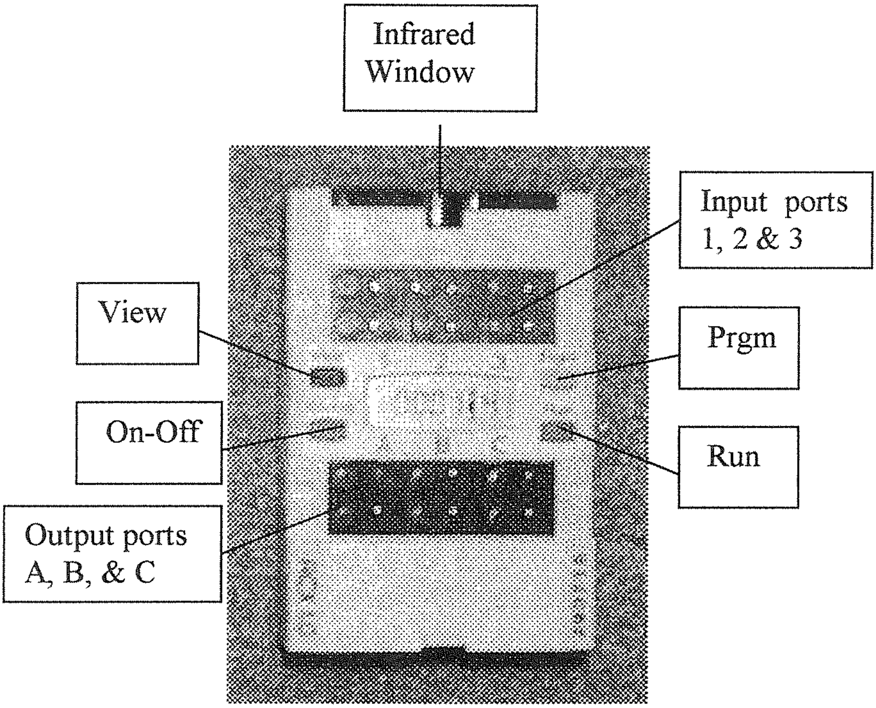
Future studies should be designed to refine the teaching model and further study problem solving abilities. Suggested course modifications include lengthening the course and providing the students with pre-built robots early in the course so that they can concentrate on thoroughly learning the programming. This will remove the strong attraction to play with the LEGO bricks when it is programming skills that should be concentrated on. After students have a good command of the programming environment the design and analysis aspects of the project can be introduced.

The American public education system demands that teachers better prepare students for entry into college and the workplace. The US Secretary of Labor, ISTE, and South Carolina science and math standards include problem-solving skills in the list of skills that students are expected to master. If teachers are to succeed, they must be offered models and assessment tools to utilize in these classes.

Appendix A:

LEGO Hardware and Robolab Programming

RCX: (Robot Command System) A programmable LEGO brick.



Buttons	
On-off	Turns the brick on and off.
Prgm	Allows the user to run a specific program. The RCX can store up to 5 programs.
Run	Begins the selected program.
View	Allows for monitoring of a specific port.

Figure 7: RCX Brick

It controls the robot's motors and lights and processes information received from sensors. The RCX allows the robot to act autonomously. It operates on a Hitachi H8 8 bit microcontroller running at 5 to 20 MHz with 32 K or RAM (Hystad, 2002).

The RCX operates on 6 AA batteries or an AC adapter. The RCX will automatically power down after 15 minutes, however, the user can change the power down time to anywhere from 1 to 255 minutes.

The RCX can communicate with other RCX bricks or a computer. It also contains a piezoelectric speaker that is capable of producing 6 tones.

Infrared Transmitter: The legacy transmitter utilizes a serial port. The serial port infrared transmitter requires a 9 volt battery. A USB port infrared transmitter is also available and does not require battery power. The infrared transmitter is used to download programs from the computer or for RCX-RCX communications.

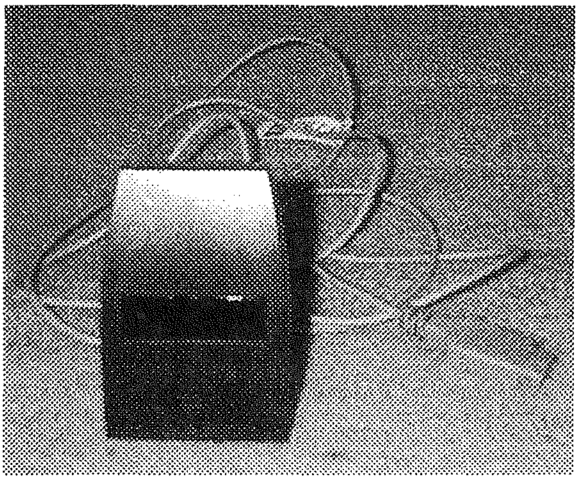


Figure 8: Infrared Transmitter

Input Devices: The RCX has the ability to connect up to three input devices.

Light sensor: A 2 X 4 LEGO brick that contains a red light emitting diode (LED) and a phototransistor. It operates by lighting the area in front of the brick and reading the reflected light.

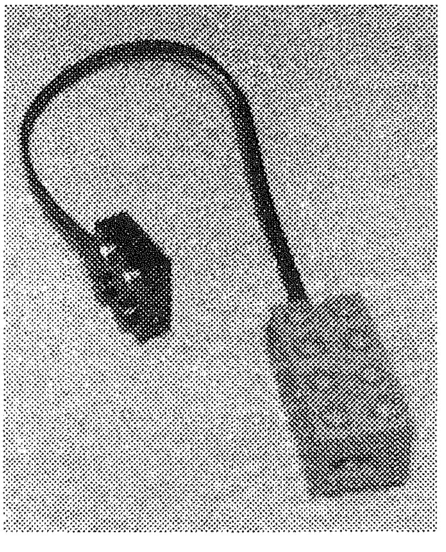


Figure 9: Light Sensor

Touch sensor: A 2 X 3 brick with a digital sensor that allows the robot to change behaviors when the sensor is depressed or released.

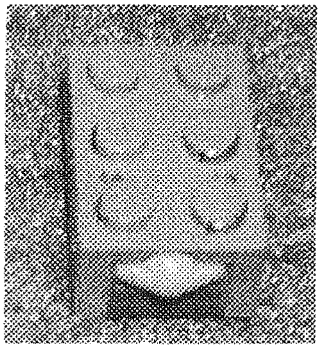


Figure 10: Touch Sensor

Output Devices: The RCX has the ability to connect up to three output devices.

9 volt motor with gear reduction: This motor has an internal gear train with a 12:1 gear reduction and connects to the RCX via snap on leads. Students used this motor to provide power to the wheels of robots.

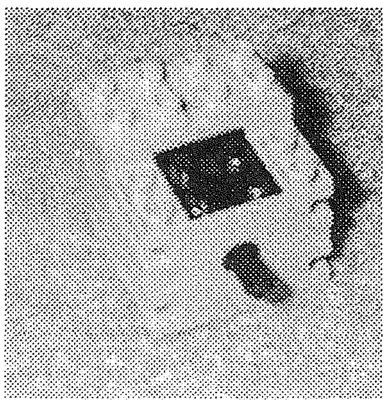


Figure 11: Micromotor with Gear Reduction

Micromotor: Used to rotate specific elements of the robot.

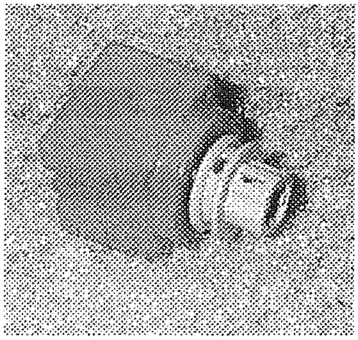


Figure 12: Micromotor

Lamp brick: Provides light.

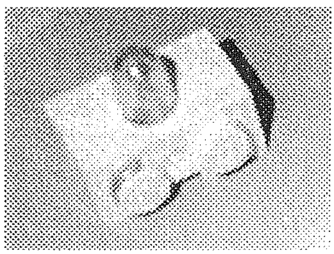


Figure 13: Lamp Brick

Programming:

Firmware: The operating system of the RCX. The user must download firmware before the RCX can receive a Robolab program.

Robolab: The icon based program that the programmer uses to write programs for the robot. There are two programming options: Pilot and Inventor. Pilot programming is introductory. It includes tutorials and templates that can be modified. There are four levels of Pilot programming; however, all functions of the program are not available at this level.

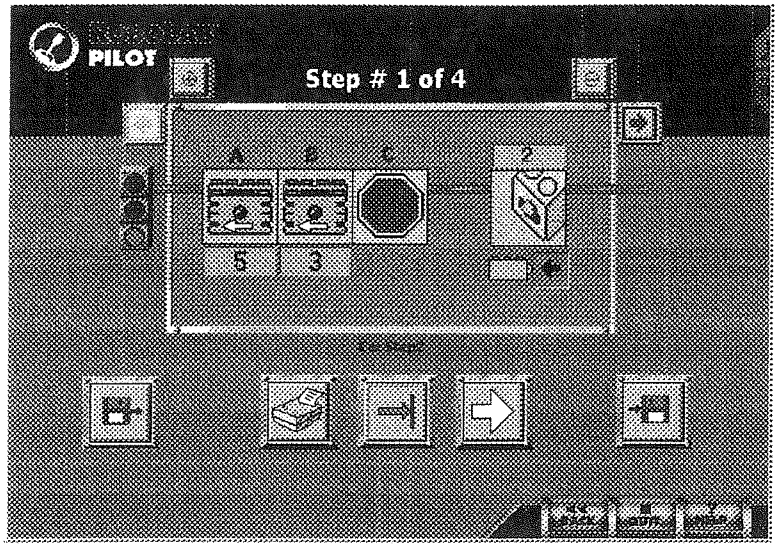


Figure 14: Sample Pilot Level Programming Screen

Inventor programming is more robust. The programmer can pick and place icons into a programming window. Wiring the icons together completes the programming. This option also has four levels of programming with level four providing the ability to write complex programs.

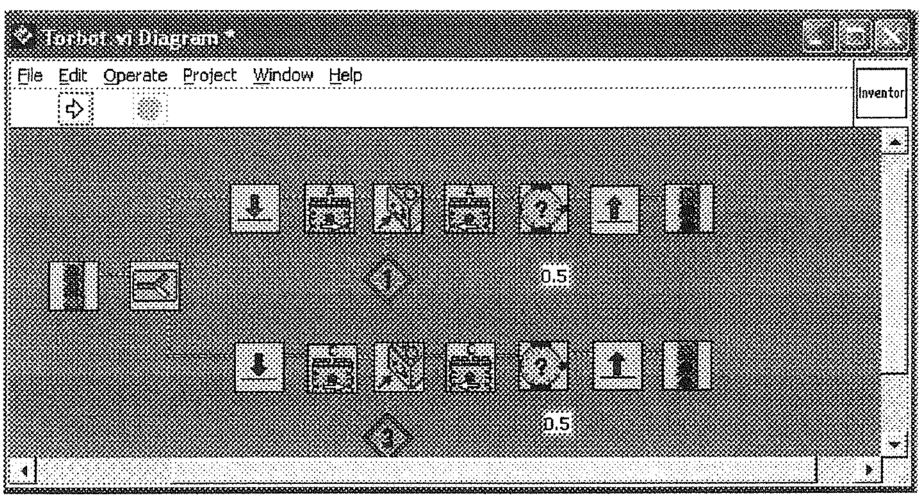


Figure 15: Sample Inventor Level Programming Window

Appendix B

South Carolina 7^{th} Grade Science Standards

Bold print indicates SC science standards. Standard print indicates how the standard was integrated into the project.

Inquiry-Abilities Necessary to do Scientific Inquiry Including:

1. **Observe patterns of objects and events.** The robot's performance was observed in order to judge whether it has met the criteria specified within the project.

2. **Classifying or arranging data in sequential order.** Programming must be done in a sequential order if the robot is to perform as specified.

3. **Selecting and using appropriate tools.** The appropriate blocks must be selected and used in order to construct the robot from LEGO pieces.

4. **Making inferences based on observations.** If the robot does not perform as expected the team must infer how to correct the problem based on its observed behavior.

5. **Predicting the results of actions based on patterns in data and experiences.** The Robolab program written by the student group served as a prediction of how the robot behaved.

6. **Selecting and using appropriate tools and technology (such as computers and probes) to perform tests, collect data, and display data.** Sensors, computers, and probes were necessary components of the student-constructed robots.

7. **Reviewing and summarizing data to show cause-effect relationships in experiments.** Student constructed programs caused an effect that was expressed through the robot's actions.

8. **Analyzing different ideas and explanations to consider alternative ideas.** When students work as a group they proposed and evaluated options offered by group members. They needed to come to a consensus as to which proposal would be developed into the program that directed the robot.

9. **Accepting the skepticism of others as part of the scientific process.** As in all group activities it was necessary for group members to agree to disagree in order to develop one program that met the project's criteria.

10. **Using drawings and written and oral expression to communicate information.** Students kept journals recording their experiences during the project.

11. **Creating and/or using scientific models to communicate information.** The actions of the model robots communicated the program's ability to carry out the directives of the project.

12. **Using mathematics to gather, organize, and present data.** Students used programming skills to write computer programs that controlled the model robot. The program contained the data that determined whether or not the robot performed according to the specified criteria.

13. **Determine whether a product will meet the identified need.** The students determined whether their robot met the needs as specified by the project rules.

14. **Communicating ideas with drawings and simple models.** As part of the journal students sketched the model they built and outlined the program they constructed.

15. **Selecting suitable tools and techniques to ensure adequate accuracy.** Tools like meter sticks were used to measure the robot's actual performance.

16. **Organizing materials, devise a plan and work collaboratively where appropriate.** Student work groups were collaborative groups of four or five students.

17. **Measuring the quality of the product based on the original purpose or need and the degree to which it meets the needs of the users.** Students used measurement tools to determine whether or not the robot met the design criteria and performed as expected.

18. **Suggest improvements and try proposed modifications to the design.** The journaling portion of the project provided students with the means to record suggested improvements to the robot. They re-tested the robot's performance to see if flaws were corrected.

19. **Identifying the four stages of problem solving: problem identification, solution design, implementation, and evaluation.** The basis of the project's design is Polya's (1959) four stages of problem solving.

20. **Explain why constraints on technological design are unavoidable.** Students reflected on the constraints that the LEGO blocks place on the robots.

Appendix C:

6^{th}, 7^{th}, 8^{th} Grade Math Standards

Bold print indicates SC math standards. Standard print indicates how the standard was integrated into the project.

Process—Problem Solving (SC Department of Education, 2003)

1. **Build new mathematical knowledge through problem solving.** The robotics project required students to construct Robolab programs. The programs were designed to control an autonomous robot that met specified criteria.

2. **Solve problems that arise in mathematics and in other contexts**. Students designed robots that met the requirements posed within the problem.

3. **Apply and adapt a variety of appropriate strategies to solve problems**. Devising a workable solution to the problem required students to revisit their programs and robots and revise them until the robot performed as needed.

4. **Monitor and reflect on the process of mathematical problem solving.** The journals required students to keep written records and reflections on the processes involved in programming, robot construction, and performance. Entry guidelines were developed based on George Polya's problem solving methods (Polya, 1957).

5. **Recognize reasoning and proof as fundamental aspects of mathematics.** Student reasoning guided the development of the Robolab programs.

6. **Make and investigate mathematical conjectures.** Student conjectures about the behavior of the robot guided programming attempts.

7. **Organize and consolidate mathematical thinking through communication.** Verbal and written communication served as ways to document student thinking in the problem solving process.

8. **Communicate mathematical thinking coherently and clearly to peers, teachers, and others.** Appropriate robot performance was the final communication that combined the programming and construction skills required for students to solve the project problem.

9. **Analyze and evaluate the mathematical thinking and strategies of others.** Students worked in cooperative groups throughout the project. This required them to consider the thinking and strategies proposed by others within the group.

10. **Recognize and use connections among mathematical ideas.** To create an operational robot students connected the mathematical ideas involved in programming and construction to the real world. The robots performed in the real world based on the student written program. In addition, it operated within the physical constraints of the materials from which it was constructed.

11. **Understand how mathematical ideas interconnect and build on one another to produce a coherent whole.** The mathematical program directed a three dimensional object to perform within the three dimensional world. Students used logical mathematics skills as well as spatial visualization skills in the programming and construction of the robots.

12. **Recognize and apply mathematics in contexts outside of mathematics.** The project provided students with early insights into the engineering field. Mathematical concepts were used to solve a problem and to design and create objects that perform a task that is specified by humans.

13. **Use representations to model and interpret physical, social, and mathematical phenomena.** Student journals included sketches and drawings of programs and robot construction ideas.

Algebra (Middle School)—Understand patterns, relations, and functions.

1. **Describe, extend, analyze, and create a wide variety of patterns to investigate relationships and to solve problems (grade 7).** Examination of relationships between the program, the physical construction of the robot, and the behavior of the robot was required for the robot to perform and solve the problem posed.

2. **Use different forms of representing information (grade 7).** Both the Robolab program and the robot hold information needed to solve the problem. Student participants in the projects generated both types of information.

3. **Explain the use of a variable as a quantity that can change its value, as a quantity on which other values depend, and as generalization of patterns (grade 7).** Each line of the program represents a specific quantity of the robot's behavior. Changing the robot's behavior depended on changes in the program or changes in its physical structure.

Measurement—Apply Appropriate Techniques, Tools, and Formulas to Determine Measurements.

1. **Analyze a variety of measurement situations to determine the necessary degree of accuracy and precision. (grade 7)** Students programmed the robot

so that it was capable of maneuvering through space according to directions given in the problem.

Appendix D:

ISTE Technology Standards

Grade K-2--Skill Reinforcement of Basic Operations and Concepts

1. **Communicate about technology using developmentally appropriate and accurate terminology.** Student/Investigator communications about the LEGO technology and the project were both verbal and written.

2. **Use developmentally appropriate multimedia resources (educational software) to support learning.** Student use of the Robolab software was integral to developing the program that ran the robot.

3. **Demonstrate positive social and ethical behaviors when using technology.** The final product resulted from the cooperative work of the student group.

4. **Use a variety of media and technology resources for directed and independent learning activities.** The Robolab technology was a new resource for student learning. The project utilized both directed and independent components. Students were given problems to solve; however, the solutions devised were independent.

1. **Use technology resources for problem solving, communication, and illustration of thoughts, ideas, and stories.** The Robolab technology was used for solving the problem as well as creating and operating the robot. Communication and illustrations of student progress were kept in a journal.

Grade 3-5--Skill Reinforcement of Basic Operations and Concepts

1. **Use keyboards and other common input and output devices efficiently and effectively.** Input devices were used in programming and journaling activities.

2. **Discuss basic issues related to responsible use of technology and information; and describe personal consequences of inappropriate use.** Responsible use of the technology resulted in all students participating in the activities. Consequences for irresponsible use were expected to vary depending on the severity of the misuse. In order to keep the technology operational students were required to comply with responsible behavior or be removed from the project so that others could continue learning.

3. **Use technology tools for individual and collaborative writing, communication and publishing activities to create knowledge products for audiences inside and outside the classroom.** As a culminating activity

of the project students showcased their programming and robot construction skills in a drag race for the class.

4. **Use technology resources for problem-solving, self-directed learning and extended learning activities.** The Robolab software and robot construction system allowed students to use computer technology to explore all facets of problem solving through activities that were both self-directed and based in the real-world.

Grades 6-8

1. **Apply strategies for identifying and solving routine hardware and software problems that occur during everyday use.** Students needed to solve technology problems in order to make certain that the robot performed as required.

2. **Use content-specific tools, software and simulations to support learning and research.** The Robolab system was selected specifically to support this goal.

3. **Design, develop, publish and present products using technology resources that demonstrate and communicate curriculum concepts to audiences inside and outside the classroom.** The robot was the product that was designed and developed for a classroom audience.

4. **Select and use appropriate tools and technology resources to accomplish a variety of tasks and solve problems.** Students selected appropriate LEGO pieces in order to construct robots that perform as required.

5. **Demonstrate an understanding of concepts underlying hardware, software, and connectivity, and practical applications to learning and problem solving.** Students presented evidence of these activities through programming, sensor selection, and use of the Robolab system.

Appendix E:

SCANS Competencies in Management and Use

Bold print indicates the SCANS competency. Standard print indicates how the competency was integrated into the project.

1. **Resources--Workers schedule time, budget, funds, arrange space, or assign staff.** Successful completion of the project indicated that students managed time and materials well.

2. **Interpersonal Skills --Competent employees are skilled team members and teachers of new workers. They negotiate with others to solve problems or reach decisions; they work comfortably with colleagues from diverse backgrounds; and they responsibly challenge procedures and policies.** Students worked in cooperative groups and together they decided how to construct an autonomous robot that solved the problem posed. Groups were designed to be as diverse as possible.

3. **Information--Workers are expected to identify, assimilate, and integrate information from diverse sources; they prepare, maintain, and interpret quantitative and qualitative records; they convert information from one form to another and are comfortable conveying information and in writing, as the need arises.** Student journals provided a record of progress throughout the project. They recorded information that detailed their thinking and decisions. Problems and robot redesign information were included. Verbal communications with the researcher were ongoing throughout the project.

4. **Systems--Workers should understand their own work in the context of the work of those around them; they understand how parts of systems are connected, anticipate consequences, and monitor and correct their own performance; they can identify trends and anomalies in system performance, integrate multiple displays of data, and link symbols (e.g., displays on a computer screen) with real phenomena (e.g., machine performance).** Students wrote the Robolab programs based on the expected performance of the autonomous robot. If the robot performed as expected they understood the symbolism involved in writing the program and how it translated into the behavior pattern of the robot. If the behavior was not what they expected they identified the problem and changed the program to correct the robot's behavior.

5. **Technology--Technology today is everywhere, demanding high levels of competence in selecting and using appropriate technology, visualizing operations, using technology to monitor tasks, and maintaining and troubleshooting complex equipment.** Although students were provided with suitable technology they were required to visualize the robot's behavior in order to write an appropriate program. Construction of the robot occurred concurrently with

the writing of the initial program. Troubleshooting occurred when they downloaded the program to the robot and tested whether or not it performed according to the specifications provided. If it did not behave as expected they re-evaluated and changed the program and re-tested the robot.

Appendix F: Student Individualized Performance Rubric

(R. Custer, personal communication, October 17, 2003)

Problem & Design Clarification

	Expert	Proficient	Competent	Beginner	Novice
Examine context & define problem	Poses pertinent questions for clarification. Identifies and prioritizes sub-problems (within the larger problem). Explores context.	Poses questions. Identifies sub-problems but does not prioritize. Ignores context.	Asks some pertinent questions. Identifies key content. Defines problem adequately. Ignores context.	Expresses limited knowledge of context or problem; problem is defined but needs clarification. Asks questions but not pertinent and too few. Ignores context. Exhibits some indifference or frustration.	Tends to hone in on wrong problem, isolated subset, or easiest part to solve. Begins to solve without clarification or questions. Doesn't see context. Exhibits considerable indifference or frustration.
Develop, clarify, & negotiate constraints and criteria	Explains key constraints in detail. Tries to negotiate or circumvent constraints. Clarifies criteria prior to solving	Clarifies constraints in detail; expresses their relationship to the problem solution. Engages in limited negotiation of the constraints.	Clarifies constraints and accepts them as presented and understood.	Recognizes constraints but seeks minimal clarification. Accepts constraints as is. Clarifies constraints late in design process as failures occur.	Does not identify constraints or criteria; does not grasp the significance of constraints. Sees constraints as insignificant.

	problem or posing solutions.				
Conduct research/gather pertinent information	Consults several key sources. Evaluates information; relates information back to problem and constraints. Uses refined search strategies. Researches sub-problems	Consults several key sources. Uses observational techniques. Cites references. Ignores sub-problems.	Uses search guides and locates at least 2 sources. Consults sources with some direction and/or organization.	Conducts very limited research. Search restricted to easy-to- find and readily available resources.	Does not conduct research nor consult sources. Starts solving problem without information.

Develop a Design

	Expert	Proficient	Competent	Beginner	Novice
Generate and visualize possible solutions	Generates creative and efficient solutions. All solutions meet constraints and address the original problem. Able to generate a number of different solutions. Is innovative	Generates feasible solutions, but many are similar. Meets constraints. Uses resources efficiently. Proposes creative solutions. Thinks "inside of the box.	Generates solutions that meet most of constraints. Establishes resources needed to implement solution. Generates several possible solutions within constraints. Thinks "inside the box.	Identifies solutions that meet some of the constraints. Some solutions are adequate to solve the problem. Solutions may/may not be feasible. Identifies single solution that meets constraints.	Cannot identify solutions *or* solutions are inappropriate to framed problem. Does not appear to have an idea of where to begin. Solutions are disconnected from, or totally ignore, constraints.
Select a design solution	Provides detailed reasons for selecting solution. Provides backup or alternate solution in case the first solution fails. Attempts to be	Selects solution on basis of efficiency and effectiveness. Checks against constraints. Provides basic rationale for	Selects a reasonable solution based on criteria. Solution meets constraints.	Selects solution with limited attention to criteria. Can select solution. Solution may or may not be feasible. Is tentative and	Selects solution according to personal preferences. Unable to decide solution. Solution may be unrealistic or

	innovative and wants best possible solution. Self-assured.	selection. Tends not to have an alternative solution in case the initial choice does not work.		insecure in the selection process.	impractical. Uses few if any criteria to evaluate solutions. Solution represents an easy way out.
Plan & communicate design	Develops detailed design plan, drawings, and sketches. Devotes careful attention to constraints. Continuously revisits and refines the solution. Knows when to stop the refinement process.	Creates a plan with supporting technical drawings. Maintains journal or log of daily activities. Meets constraints.	Creates an organized plan with sufficient detail. Identifies basic tools, resources. Visualizes using technical drawings. Ignores some constraints.	Explains design plan, citing procedures, resources, and other requirements. Visualizes using technical sketches without regard for scale. Ignores key constraints.	Explains design in general terms and with little detail. Sketches are rough and without sufficient detail. May attempt to move forward without drawings. Ignores constraints.

Model/Prototype

	Expert	Proficient	Competent	Beginner	Novice
Select and use resources	Uses appropriate resources (i.e. tools, materials, and information) for developing and producing the solution. Accesses a variety of information sources (websites, manuals, technicians, electronic catalogs, etc.). Selects and adeptly uses resources.	Accesses and uses appropriate resources to solve the problem. Exhibits refined knowledge of tools, materials, and technological processes. Uses resources confidently.	Selects and uses appropriate resources related to most aspects of the problem. Displays some difficulty in accessing information. Selects appropriate tools for developing and producing the solution. Search for resources is limited to few sources.	Selects a limited range of resources. Some difficulty in choosing appropriate technological resources. Needs guidance in safe use of resources.	Limited ability to select and use basic resources. Selection of tools, materials, processes, and information may be inappropriate. Selected resources may not be feasible due to lack of availability, need for expertise, or cost.
Develop a plan for producing a model/prototype	Develops a well detailed plan with references to design constraints and criteria. Includes testing and	Develops a detailed and systematic plan. Communicates information and processes needed to produce the model or	Develops a plan with logical and sufficient steps to develop and produce a solution. Plan needs quality control checkpoints.	Develops a plan with some gaps and insufficient steps to solve the problem. Connection with design criteria and constraints is	Develops a plan that lacks coherence and departs from design constraints and criteria. Plan contains gaps and does not flow

	modification steps. Incorporates quality control measures.	prototype. Incorporates testing as a procedural step.		marginal.	logically. Procedures lack necessary detail.
Produce model/prototype	Is adept with tools and resources, making continual adjustments to "tweak" the model/prototype. Demonstrates persistence with minor problems. Enjoys the challenge of refinements.	Uses tools and resources without guidance. Refines model to enhance appearance and capabilities.	Uses tools and resources with little or no guidance. May redo model/prototype parts to improve quality.	Uses tools and resources with some guidance. May have difficulty selecting appropriate resources. Refines work, but may prefer to leave model as first produced.	Needs guidance in order to use resources safely and appropriately. Crudely constructs model/prototype, with little or no refinement.

Evaluate the Design Solution

	Expert	Proficient	Competent	Beginner	Novice
Test and critique solution	The solution fully meets the design constraints and criteria. Specific improvement ideas are generated and documented.	The solution meets most of the design constraints and criteria. Some general improvement ideas are generated and documented.	The solution addresses some design criteria completely but ignores others. Recognizes the need for improvement. Some ideas are generated, however only in concept. Documentation is sketchy.	The solution is only marginally connected with the design criteria. Shows little interest in improving the solution.	The solution fails to meet selected design criteria. In spite of problems detected during testing, no effort is made to refine the solution.
Refine solution	Solution is refined in a manner consistent with constraints and criteria. Solution is in constant refinement, based on continuous data gathering.	Solution is refined in a manner consistent with constraints. Changes represent some improvement to the quality and functionality of the solution.	Solution is refined to be consistent with design constraints and criteria. Refinements may be cosmetic and may not be significant.	Some minor refinement of the original solution. Refinements are primarily cosmetic in nature and contribute only marginally to the quality or effectiveness of the	Solution is accepted "as is". Criteria and constraints are not referenced. No data is collected to evaluate the solution.

				solution.	
Documentation/Technical Reporting	All aspects of the design process are well documented; including the processes used, design details, and resources. Documentation package is well organized, highly reflective, technically accurate, and communicates effectively to others.	The design process is documented including the processes used, design details, and resources. Drawings are technical and provide essential information Documentation is fairly organized. Some insights concerning design changes and refinements are detailed.	Documentation of design processes are factual and include all components. Drawings are technical and provide essential information. Reflections are limited to facts, with limited depth.	Some attention to documentation with a preference for graphically depicting the design. Little evidence of a clear organizational scheme. Some design stages may not be documented.	Little documentation is done of either the product design or of the design process. Documentation is limited to hand-drawn sketches and sketchy, handwritten notes.

Appendix G

Lesson Plans

Lesson: 1

Topic: Problem solving

Objective: 1. To introduce students to the format of TABE-PS and to dispel any mystery surrounding the test. 2. To obtain a baseline of student work-related problem solving skills using the Tabe-PS Form 7.

Standards: N/A

Instructor Preparation: Become familiar with the test including instructions for administering and answering student questions. (10 minutes), Become familiar with the TABE-PS, directions for administering the test, and procedures for scoring the test. (1 hour).

Student Materials: 1 practice exercise, 1 TABE-PS Form 7, number 2 pencil with eraser, scratch paper, calculator (to be used at student discretion).

Instructor Materials: Examiner's Manual/Scoring Guide, extra pencils, timepiece

Introduction: Distribution of practice exercise and directions. Students complete practice exercises (15 minutes).

Practice: Students take the TABE-PS Form 7. (60 minutes)

Closure: Collect materials/ verbal student feedback. (5 minutes)

Assessment: Use the Scoring Guide to evaluate the correctness of student responses.

Evaluation of Problem Solving Skills: After completion of scoring, record mastery of competency level scores on IDP. Enter all student mastery scores in Table 15 Mastery of Competencies.

Table 15: Group Mastery of Competencies (Sample Chart)

Student ID	Competencies			
	1	2	3	4

Lesson: 2

Topic: Teambuilding.

Objective: To foster development of the concept that products are designed and problems are solved by working as a team.

Standards:

SC Science:

Inquiry-Abilities Necessary to do Scientific Inquiry Including:

Analyzing different ideas and explanations to consider alternative ideas.

Accepting the skepticism of others as part of the scientific process.

Using drawings and written and oral expression to communicate information.

Organizing materials, devise a plan and work collaboratively where appropriate.

ISTE Technology Standards:

Use content-specific tools, software and simulations to support learning and research.

Design, develop, publish and present products using technology resources that demonstrate and communicate curriculum concepts to audiences inside and outside the classroom.

Instructor Preparation: Place students into groups and give each group a distinct identification number. (30 minutes)

Materials: One computer per group loaded with Microsoft Word, 1 floppy disk per group.

Introduction: Place students into groups and introduce them to the idea of working together as a team to accomplish tasks and solve problems. (10 minutes)

Development: Demonstrate the use of the drawing toolbar within Word, explain that students will come up with a team logo that will represent them throughout the project, and answer student questions (10 minutes). Note: Many students are familiar with the Word drawing capabilities so time for a quick review is allotted.

Practice: Students brainstorm names for their team. (10 minutes)
Students select a team name from the list they generated. (5 minutes)
Students create a team logo using the Word drawing tools. Final logo is saved to a floppy disk and returned to the instructor for display on the project website. (30 minutes)

Closure: Students display their team logos to the class. (10 minutes)
Students complete journal entry. (10 minutes)

Assessment: Field notes

Journal: Team Building

1. What is the best thing about working as a team?

2. What is the worst thing about working as a team?

3. What does your group's logo mean? Why did you choose it?

Lessons: 3-12

Topic: Robotic Missions

Objective: To introduce students to mechanical engineering concepts and programming.

Standards:

Inquiry-Abilities Necessary to do Scientific Inquiry Including:

Observe patterns of objects and events.

Classifying or arranging data in sequential order.

Making inferences based on observations.

Predicting the results of actions based on patterns in data and experiences.

Reviewing and summarizing data to show cause-effect relationships in experiments.

Analyzing different ideas and explanations to consider alternative ideas.

Accepting the skepticism of others as part of the scientific process.

Using drawings and written and oral expression to communicate information.

Creating and/or using scientific models to communicate information.

Using mathematics to gather, organize, and present data.

Mathematics—Process-Problem Solving

Monitor and reflect on the process of mathematical problem solving.

Make and investigate mathematical conjectures.

Organize and consolidate mathematical thinking through communication.

Analyze and evaluate the mathematical thinking and strategies of others.

Recognize and use connections among mathematical ideas.

Describe, extend, analyze, and create a wide variety of patterns to investigate relationships and to solve problems.

Use different forms of representing information

Explain the use of a variable as a quantity that can change its value, as a quantity on which other values depend, and as generalization of patterns.

ISTE Technology Standards:

Use content-specific tools, software and simulations to support learning and research.

Demonstrate an understanding of concepts underlying hardware, software, and connectivity, and practical applications to learning and problem solving.

Materials:

Class: One reference copy of *Building Lego Robots for FIRST LEGO LEAGUE* (Hystad, 2002)

Group: 1 computer with Robolab software, infrared transmitters with cables, construction kits for groups to construct robots, write and download programs, 1 floppy disk per group, 2 copies of the Mission Manuals (Appendix H) and 2 copies of Mission Technical Specifications 9780, 1 copy of *Using Robolab* (Cyr, 2002)

Individual: Mission Journal

Instructor Preparation: Separate LEGO elements into separate kits so that students are able to build and test the robot (3 hours)

Introduction: Students are introduced to the six robot kits available. Each group will construct five robots. The robots are constructed from the LEGO Mindstorms for School starter set and include: My House, Torbot, The Car, and The Gadget. In addition, two challenge kits were available. The Bug and the Human Habitat challenge were adapted from the original LEGO instructions to offer more open ended and challenging projects for those groups that were capable of working with fewer instructions.

Development: Students follow the Technical Specifications of the Mission and the directions in the "Mission Manuals" to complete the mission. In the process students learn to program as well as how and when to use LEGO elements like lamp bricks, two types of motors, touch and light sensors, gears, and different types of wheels

Groups work on each mission for two periods

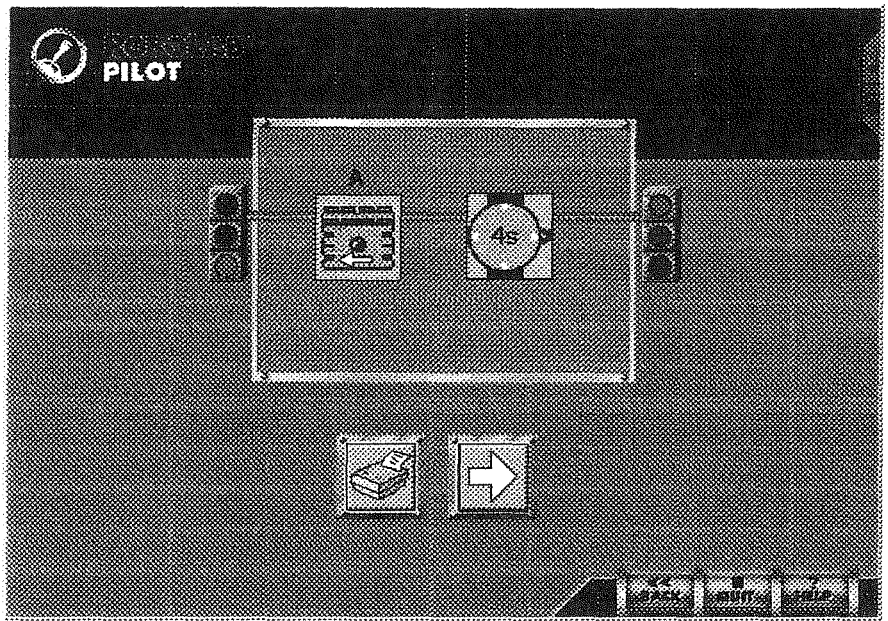
Closure: Students reflect on the day's programming activities in journals.

Assessment: Journal entry and SIP at the end of Mission 1.

Evaluation: Score journal for correct answers. Scores will be quantitative (percentage of correct answers) as well as qualitative as appropriate.

Note: Although each mission started with a pre-designed lesson each group utilized part of each class to practice their design and programming skills by altering robots to their own designs.

Robotics Journal Entry 2



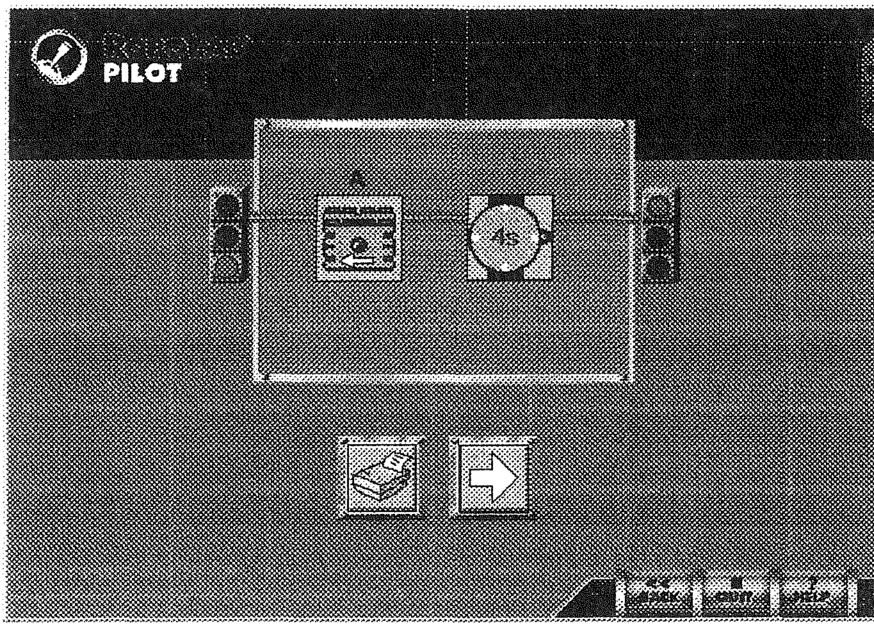
1. What does this program mean?

2. Re-write the program and change the amount of time that the car will travel.

3. Re-write the program and change the direction that Motor A Moves.

4. Draw a RCX brick and label the following parts:
    - Input ports
    - Output ports
    - Power button
    - Run button
    - Change Program button
    - Infrared window

Robotics Journal Entry 2 (Answer Key)



1. What does this program mean?

The green light means start the program then run motor A in reverse for 4 seconds then stop.

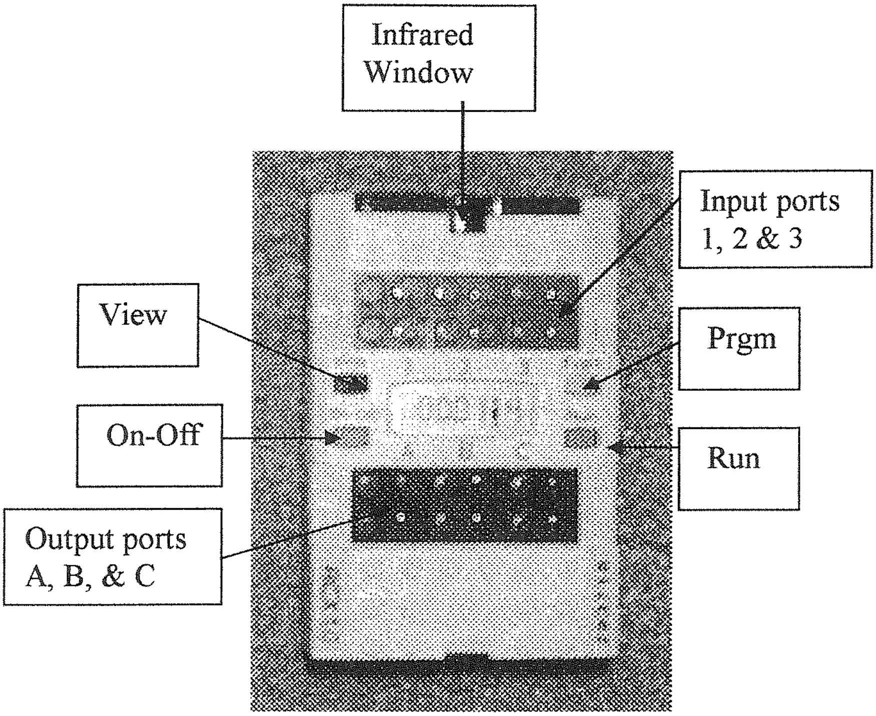
2. Re-write the program and change the amount of time that the car will travel.

The green light means start the program then run motor A in reverse for 6 seconds then stop. (Accept any reasonable answer that changes the time.)

3. Re-write the program and change the direction that Motor A Moves.

The green light means start the program then run motor A forward for 2 seconds then stop.

4. Draw a RCX brick and label the following parts:
   - Input ports
   - Output ports
   - Power button
   - Run button
   - Change Program button
   - Infrared window


Infrared Window
Input ports 1, 2 & 3
View
Prgm
On-Off
Run
Output ports A, B, & C

Lesson: 13

Lesson 9

Topic: Problem solving method

Objective: To introduce students to the problem solving method

Standards:

Science Inquiry-Abilities Necessary to do Scientific Inquiry Including:

Observe patterns of objects and events.

Classifying or arranging data in sequential order.

Making inferences based on observations.

Analyzing different ideas and explanations to consider alternative ideas.

Accepting the skepticism of others as part of the scientific process.

Using drawings and written and oral expression to communicate information.

Identifying the four stages of problem solving: problem identification, solution design, implementation, and evaluation.

Mathematics:

Build new mathematical knowledge through problem solving.

Apply and adapt a variety of appropriate strategies to solve problems.

Organize and consolidate mathematical thinking through communication.

Given a problem situation, determine the type of solution needed and an appropriate technique.

Materials: Problem Solving PowerPoint Presentation (Appendix I), computer, projector

Instructor Preparation: Become familiar with presentation.

Introduction: Whole class presentation of slides 1-3 of presentation. Have the class list a problem that they think the Sojourner robot needs to solve. (5 minutes)

Development: Whole class presentation of slides 4-7 on Polya's problem solving steps.

Practice: Whole class presentation of slides 10-11. Groups use journals to interpret the diagram into a problem to be solved, and write a plan to solve it. Included are questions about constraints and criteria and an algorithm. (40 minutes)

Closure: Group discussion problem and plans to solve it. (20 minutes)

Assessment: Group journal entries.

Lesson: 14-17

Topic: 1. Student groups are challenged to construct a robot that win a drag race.
2. Student groups design a robot of their choice that best demonstrates the principles of robot design and programming.

Standards:

Science: Inquiry-Abilities Necessary to do Scientific Inquiry Including:

Observe patterns of objects and events.

Classifying or arranging data in sequential order.

Selecting and using appropriate tools.

Making inferences based on observations.

Predicting the results of actions based on patterns in data and experiences.

Reviewing and summarizing data to show cause-effect relationships in experiments.

Analyzing different ideas and explanations to consider alternative ideas.

Using drawings and written and oral expression to communicate information.

Creating and/or using scientific models to communicate information.

Using mathematics to gather, organize, and present data.

Communicating ideas with drawings and simple models.

Organizing materials, devise a plan and work collaboratively where appropriate.

Suggest improvements and try proposed modifications to the design.

Mathematics—Problem Solving:

Make and investigate mathematical conjectures.

Organize and consolidate mathematical thinking through communication.

Communicate mathematical thinking coherently and clearly to peers, teachers, and others.

Analyze and evaluate the mathematical thinking and strategies of others.

Recognize and use connections among mathematical ideas.

Recognize and use connections among mathematical ideas.

Recognize and apply mathematics in contexts outside of mathematics.

Use representations to model and interpret physical, social, and mathematical phenomena.

Algebra (Middle School)—Understand patterns, relations, and functions.

Describe, extend, analyze, and create a wide variety of patterns to investigate relationships and to solve problems.

Use different forms of representing information.

Explain the use of a variable as a quantity that can change its value, as a quantity on which other values depend, and as generalization of patterns.

ISTE Technology Standards:

Use content-specific tools, software and simulations to support learning and research.

Design, develop, publish and present products using technology resources that demonstrate and communicate curriculum concepts to audiences inside and outside the classroom.

Select and use appropriate tools and technology resources to accomplish a variety of tasks and solve problems.

Demonstrate an understanding of concepts underlying hardware, software, and connectivity, and practical applications to learning and problem solving.

Materials: 1 computer with Robolab, 1 robot construction kit, 1 copy of Using Robolab (Cyr, 2002)

Instructor Preparation: Separate LEGO elements into kits with the basic bricks needed for robot construction.

Introduction: Introduce students to the project by explaining that their mission is to construct a robot that can win a drag race. Show them that the drag strip is 15 feet long consisting of two lanes separated by a black strip of electrical tape on the floor. Individual car times were used to determine which cars raced each other. Race cars were limited to no more than two 9-volt with gear reduction motors, four tires (style of the group's choosing), two light sensors, one touch sensor, and no more than one foot long and wide. Extra elements including gears, beams, connectors, etc. were available to all students.

Students also worked on a robot construction that they felt would best showcase their guidelines for the final programming project:

Work will be submitted on your floppy disk. (No printing)

You must include a digital picture of the robot and the best program that you wrote to control the robot. Answer the following questions as completely as possible.

1. What was your robot built to do?
2. In order to get the robot to function properly what questions did you need answered?
3. What were some things that determined how the robot was finally constructed?
4. What resources did you use to help you complete the project?
5. How many robots did you design and build before you chose the final design?
6. Why did you choose to design the robot the way you did?
7. Explain the design of your robot giving as many details (words and sketches) as possible. Sketches can be completed on paper.
8. You were given a basic LEGO kit to design with. What additional materials did you need to complete the robot as designed?
9. Did you test the robot to make sure that it performed as you intended?
10. After your tests how did you change the robot design?
11. How do you think your robot design and programming could have been better?
12. How do you think this robotics class could be better?

Practice: Students worked in their groups to complete the challenges.

Assessment: Standings in the drag race, final journal entry, and robot performance..

Evaluation: Score journal for correct answers. Scores will be quantitative (percentage of correct answers) as well as qualitative.

Lesson: 18

Topic: Final Challenge—Drag Race

Objective: Compete in the race and demonstrate the robot and program that best showcase their programming abilities.

Standards: Science Inquiry-Abilities Necessary to do Scientific Inquiry Including:

Observe patterns of objects and events.

Classifying or arranging data in sequential order.

Selecting and using appropriate tools.

Making inferences based on observations.

Predicting the results of actions based on patterns in data and experiences.

Selecting and using appropriate tools and technology (such as computers and probes) to perform tests, collect data, and display data.

Reviewing and summarizing data to show cause-effect relationships in experiments.

Analyzing different ideas and explanations to consider alternative ideas.

Accepting the skepticism of others as part of the scientific process.

Using drawings and written and oral expression to communicate information.

Creating and/or using scientific models to communicate information.

Using mathematics to gather, organize, and present data.

Determine whether a product will meet the identified need.

Communicating ideas with drawings and simple models.

Selecting suitable tools and techniques to ensure adequate accuracy.

Organizing materials, devise a plan and work collaboratively where appropriate.

Measuring the quality of the product based on the original purpose or need and the degree to which it meets the needs of the users.

Suggest improvements and try proposed modifications to the design.

Identifying the four stages of problem solving: problem identification, solution design, implementation, and evaluation.

Explain why constraints on technological design are unavoidable.

Math Problem Solving

Build new mathematical knowledge through problem solving.

Solve problems that arise in mathematics and in other contexts.

Apply and adapt a variety of appropriate strategies to solve problems.

Monitor and reflect on the process of mathematical problem solving.

Recognize reasoning and proof as fundamental aspects of mathematics.

Make and investigate mathematical conjectures.

Organize and consolidate mathematical thinking through communication.

Communicate mathematical thinking coherently and clearly to peers, teachers, and others.

Analyze and evaluate the mathematical thinking and strategies of others.

Recognize and use connections among mathematical ideas.

Understand how mathematical ideas interconnect and build on one another to produce a coherent whole.

Recognize and apply mathematics in contexts outside of mathematics.

Use representations to model and interpret physical, social, and mathematical phenomena.

Algebra (Middle School)—Understand patterns, relations, and functions.

Describe, extend, analyze, and create a wide variety of patterns to investigate relationships and to solve problems.

Use different forms of representing information.

Explain the use of a variable as a quantity that can change its value, as a quantity on which other values depend, and as generalization of patterns.

Measurement—Apply Appropriate Techniques, Tools, and Formulas to Determine Measurements.

Analyze a variety of measurement situations to determine the necessary degree of accuracy and precision.

Algebra I—Algebraic expressions in problem-solving situations.

Given a problem situation, determine the type of solution needed and an appropriate technique.

Technology Standards

Apply strategies for identifying and solving routine hardware and software problems that occur during everyday use.

Use content-specific tools, software and simulations to support learning and research.

Design, develop, publish and present products using technology resources that demonstrate and communicate curriculum concepts to audiences inside and outside the classroom.

Select and use appropriate tools and technology resources to accomplish a variety of tasks and solve problems.

Demonstrate an understanding of concepts underlying hardware, software, and connectivity, and practical applications to learning and problem solving.

Materials: Completed dragsters and programs

Instructor Preparation: None

Introduction: Review the rules of the drag race. Reinforce that this is a friendly competition where students learn from their own work as well as the work of other groups (15 minutes). (Martin, 1994).

Development and Practice: Conduct student time trials and races until a champion racer is determined (40 minutes)

Closure: Students fine tune and demonstrate the final program designed and written.

Assessment: SIP rubric and student journal entries.

Evaluation: The teacher will grade group performance using observations, journal entries, and the SIP.

Lesson: 19

Topic: Measurement of problem solving skills

Objective: To obtain a post-test of student work-related problem solving skills.

Standards: NA

Instructor Preparation: None

Materials/Student: 1 copy of TABE-PS Form 8, number 2 pencils with eraser, scratch paper, calculator (to be used at student discretion)

Materials/Instructor: Examiner's Manual/Scoring Guide, extra pencils, timepiece

Introduction: Pass out materials, read directions, answer questions (10 minutes)

Development: NA

Practice: Students take the TABE-PS Form 8. (60 minutes)

Closure: Collect materials. (5 minutes).

Assessment: Use the Scoring Guide to evaluate the correctness of student responses.

Evaluation of Problem Solving Skills: After completion of scoring, record mastery of competency level scores on IDP. Enter all student mastery scores in Table 15: Group Mastery of Competencies.

Table 15: Group Mastery of Competencies (Sample Chart)

Student ID	Competencies			
	1	2	3	4

Appendix H:

Mission Manuals

Mission: "My House"

Mission Goal: To program and use a motor, lights, and light sensors in the construction of robots and to program the computer to play music.

Materials: RCX brick, IR transmitter, kit including all the Lego parts that you need to complete your mission.

Caution: You are responsible for returning every LEGO piece (in working condition) at the end of every class. Handle sensors and wires gently. They are delicate pieces of electronic scientific equipment.

Part 1: In this part of the mission you will learn how to program and control a motor.

Procedure:

1. Construct the house according to the directions on pages 6-9. Make sure that you handle the motor carefully. **DO NOT turn the black peg while it is attached to the motor.** It will strip the motor and it will no longer work.
2. Open the Robolab program.
3. Click Run Robolab→ Programmer→Pilot 1.
4. Change the program on the screen to the house program shown on page 9.
5. When you have your house constructed turn on the RCX. Place its IR window in front of the IR transmitter. Click on the white arrow icon in the lower center of the screen to download the program. You will hear a beep and receive a written confirmation that the screen downloaded correctly.
6. To check the program, gently lift the motor/table unit from the floor.
7. Press Run to run the program you created on the robot. Note the direction that the table turns.
8. Gently reconfigure the motor/table unit, and change the program, so that the motor can lower the table to the floor. Download it, and run the new program. Did it change the robot's behavior as you expected?

Part 2: In this part of the mission you will learn to use and program a light sensor.

Procedure:

1. Modify the house according to the directions on pages 10.
2. Open Pilot Level 4→Theme: Starter Set→ My Home Step 2.
3. A program will open but notice that it is not the same as the one on page 11. You will need to add a Step #4 by clicking on the + in the upper left hand corner of the screen.
4. Use the flashlight to explore how the light sensor controls the behavior of the robot.
5. As a team jot down your answers to the following questions. What did the motor tell the robot to do? What did the sensor tell the robot to do? Explain how the program controlled the robot's behavior? You can find the answers to these questions on the back of this page. Were you correct?

Answers:

1. The motor moves something. In this case the motor moved the table.
2. What did the light sensor tell the robot to do? It told it when to turn the lights and the motor on and off.
3. Explain how the program controlled the robot's behavior.

This is a 4-step program. Look at the program screen while you read this explanation.

Step 1:

4. The green light told the robot to "Begin running the program."
5. The three red stop signs told the computer that there was no output from A, B, or C or until something happened.
6. The icon showing the blue light sensor told the program what to wait for. It said, "Wait for the light sensor to detect when the light was greater than 55."

Step 2:

7. Then "Reverse the motor connected to Output Port A at power level 4".
8. The red stop sign says, "Turn off Output Port B".
9. Turn on the lamp connected to Output Port C at power level 5
10. The clock with the question mark says, "Wait for 1 second"

Step 3:

1. The red stop signs say, "Turn off the output from ports A & B.
2. The lamp says, " Turn on the lamp connected to Output Port C at power level 5".
3. "Wait for the light sensor to read less than 50."

Step 4:

4. Then, "Turn the motor connected to Output Port A forward at power level 4."
5. The red stop signs say, "Stop the output from Ports B & C".
6. The clock with the question mark says, "Wait for 1 second".
7. Then, "Stop the program."

Part 3: In this part of the mission you will gain practice with programming and lights and light sensors.

1. Modify the robot according to instructions on page 14.
2. Open the program shown on page 15 by clicking on Inventor 2→Starter Set→ My Home Step 3. A window containing the program and a functions window should open. Open the Help screen to make your work with new icons easier.
3. Download the program to the robot.
4. Run the program. Use the flashlight to explore how the light sensor controls the behavior of the robot.
5. Modify, download, and re-run a new program if you have time.
6. As a team jot down your answers to the following questions. What did the sensors tell the robot to do? Explain how the program controlled the robot's behavior? You can find the answers to these questions on the back of this page.

Answers:

1. What did the sensor tell the robot to do?
   The light sensor told the robot to turn on the motor and the light. It also told the robot to play a sound.
2. Explain how the program controlled the robot's behavior?
   a. The green stoplight said, "Begin the program".
   b. The Wait for brighter Icon told the sensor to read a light value that was brighter than it was set for. It is connected to Input Port 1.
   c. Then, "Reverse the motor connected in Output Port A at power level 1".
   d. Then, "Turn on the light connected to Output Port C at power level 3, for 2 seconds".
   e. Then, "Stop".
   f. The Wait for Darker Icon said, "When the light sensor reads a light value that is darker than set for to play a sound."
   g. Then, "Stop".

How did you do? Ready for another challenge? Only one more part and your mission is complete!

Task 4: In this task you will learn to use the piano function of the program.

1. Modify the robot according to the directions on pages 16 & 17. Open the program by clicking on Inventor 4→ Starter Set→My Home Step 4.
2. The program you see on page 17 will open.
3. Download and run the program.
4. Modify, download, and rerun the program if you have time.
5. As a team jot down your answers to the following question. Explain how the program controlled the robot's behavior? You can find the answer on the back of this page.

Answer: Explain how the program controlled the robot's behavior?

1. The green light says, "Begin the program".
2. Then, "Turn on the lamp connected to Output Port C at power level 5.
3. The Task Split icon (looks like a sideways Y) says, "Run multiple tasks at the same time".
4. Task 1 (the task at the top):
    a. Red Land icon tells the computer where to land when the Red Jump command is used.
    b. The Light Sensor Fork allows you to choose a path depending on when the value detected by the light sensor is greater-than or less-than the set number. If it is less than the set number the program will follow the bottom string. If it is greater than the set number the program will follow the top string.
        i. The top string says, "Turn the motor connected to Output Port A forward at power level 3 for 2 seconds".
        ii. Then, "Stop output from Output Port A".
        iii. The bottom string says, "If the light is less than the set value stop the output from Output Port A."
    c. The Fork Merge icon tells the program to merge the two strings of the fork together.
    d. Then, "Red Jump back to the Red Land position."
    e. Then, "Stop".
5. Task 2 (the task at the bottom):
    a. The Blue Land icon tells the program where to land when the Blue Jump command is used.
    b. The Wait for Darker icon says, "Wait for the light sensor connected to Input Port 1 to read less than the set value".
    c. Then, "Play the musical note "C".
    d. Then, "Play the musical note "D".
    e. Then, "Play the musical note "F".
    f. Then, "Blue Jump back to the Blue Land Position".
    g. Then, "Stop the program".

You built and programmed a house where the computer turns on and off lights, moves the table, and plays music.

Congratulations your team has completed the mission successfully!

Name______________________________ Date________________________

Journal: My House

1. Choose one pre-written program that was written for your vehicle and tell what it told the robot to do? (If it has more than 1 step tell what al the steps tell the robot to do.)

2. How did you re-write the program?

3. Did your program cause the robot to act as you expected? Explain.

4. Were you a programmer or a builder for your group? Do you like your job? Why or why not?

5. Did working in a group make your job easier? Why or why not?

Mission: "The Gadget"

Mission Goal: To program and use lights, light sensors, and touch sensors in the construction of robots.

Materials: RCX brick, IR transmitter, kit including all the Lego parts that you need to complete your mission.

Caution: You are responsible for returning every LEGO piece (in working condition) at the end of every class. Handle sensors and wires gently. They are delicate pieces of electronic scientific equipment.

Part 1: In this part of the mission you will learn how to program and control lights.

Procedure:

1. Construct the robot according to the directions on pages 6-10 of the Technical Specifications.
2. Open the Robolab program.
3. Click Run Robolab→ Programmer→Pilot 1.
4. Change the program on the screen to the Gadget program shown on page 11.
5. When you have your robot constructed turn on the RCX. Place its IR window in front of the IR transmitter. Click on the white arrow icon in the lower center of the screen to download the program. You will hear a beep and receive a written confirmation that the screen downloaded correctly.
6. Press Run to run the program you created on the robot.
7. Change the program, download it, and run the new program. Did it change the robot's behavior as you expected?

Part 2: In this part of the mission you will learn to use and program a light sensor.

Procedure:
1. Modify the robot according to the directions on pages 12 & 13.
2. Write a new program by opening Pilot Level 4→Theme: Starter Set→Gadget 2.
3. The program you see on page 13 will open. Download it to the robot.

4. Use the flashlight to explore how the light sensor controls the behavior of the robot.
5. As a team, jot down your answers to the following questions. What did the sensor tell the robot to do? Explain how the program controlled the robot's behavior? You can find the answers to these questions on the back of this page. Were you correct?

Answers:

1. What did the light sensor tell the robot to do? It told it when to turn the lights on and off.
2. Explain how the program controlled the robot's behavior.
   This is a 2-step program. Look at the program screen while you read this explanation.

Step 1:

1. The green light told the robot to "Begin running the program."
2. The three red stop signs told the computer that there was no output from A, B, or C until something happened.
3. The icon showing the blue light sensor told the program what to wait for. It said, "Wait for the light sensor to detect when the light was less than 55."

Step 2:

1. Then, "Turn on the lights connected at A & C at power level 5" and...
2. "Wait for the light sensor to read greater than 55."
3. Then, "Stop the Program."

Part 3: In this part of the mission you will learn to use and program a touch sensor. You will also learn to program the robot to do two tasks at the same time.

1. Modify the robot according to instructions on page 16-18.
2. Open the program shown on page 19 by clicking on Inventor 3→Starter Set→ Gadget Step 3. A window containing the program and a functions window should open. Open the Help screen to make your work with new icons easier.
3. Download the program to the robot.
4. Run the program. Use the flashlight to explore how the light sensor controls the behavior of the robot. Gently touch the levers to depress and release the touch sensor. What did these sensors do?
5. Modify, download, and re-run a new program if you have time.
6. As a team, jot down your answers to the following questions. What did the sensors tell the robot to do? Explain how the program controlled the robot's behavior? You can find the answers to these questions on the back of this page.

Answers:

1. What did the sensors tell the robot to do?
   The touch sensor told the robot to play a sound and turn on a light when it was depressed. The light sensor told the robot to play a sound and turn on a different light when the light level changed.
2. Explain how the program controlled the robot's behavior?
   This program has two branches for two separate tasks. Here's what it means:
   The green stoplight said, "Begin the program".
   a. The task split icon (sidewise Y) said, "Start a new task with this command to run multiple tasks at the same time."

Task 1 (the upper branch of the program) said:

a. The red land icon (downward pointing arrow) told the program where to return every time the red jump command (upward pointing arrow) is used.
b. The touch sensor icon said, "Wait for the touch sensor connected to input 3 to be pushed in and released".
c. Then, Play a sound."
d. Then, "Turn on a light connected to output A at power level 5 for one second."
e. Then, "Stop."
f. The red jump icon (upward pointing arrow) said, "Return to the Red Land command in the program."

Task 2 (the lower branch of the program) said:

a. The red land icon (downward pointing arrow) told the program where to return every time the red jump command (upward pointing arrow) is used.
b. The light sensor connected to input port 1 said, "Play a sound"
c. Then, "flash a light connected to output port C at power level 5 for one second when the amount of light changes."
d. Then, "Stop."
e. The red jump icon (upward pointing arrow) said, "Return to the Red Land command in the program."

How did you do? Ready for another challenge? Only one more part and your mission is complete!

Task 4: In this task you will practice the skills learned in Tasks 1-3.

1. Modify the robot according to the directions on pages 20 & 2. Open the program by clicking on Inventor→ Starter Set→ Gadget Step 4.
2. The program you see on page 21 will open.
3. Download and run the program.
4. Modify, download, and rerun the program if you have time.
5. As a team jot down your answers to the following question. Explain how the program controlled the robot's behavior? You can find the answer on the back of this page.

Answer: Explain how the program controlled the robot's behavior?

1. The green light says, "Begin the program".
2. The Red Land arrow tells the program where it should jump to when the Red Jump command is used.
3. The light sensor says, "Wait for the read a value that is brighter than the current value."
4. Then, "Play a sound".
5. The Zero Timer must be used whenever a timer fork or wait for timer command is used.
6. The Wait for Random Time icon tells the computer to wait for a random amount of time from 0 to 5 seconds.
7. Then, "Turn on the lamp in output port C at power level 5."
8. Then, "Wait for the touch sensor connected at input port 3 to be pushed in".
9. Then, "Choose a path depending on whether the timer is greater or less than a specified number. If the timer is greater than that number the program follows the top string. If it is less than that number it follows the bottom string."
10. The top string says, "Turn on the lamp in output port C at power level five for one second".
11. Then, "Play a sound".
12. The bottom string says, "Turn on the lamp connected to output port C at power level 5 for one second".
13. Then, "Play a sound".
14. The fork merge icon (sideways Y) tells the computer to merge the two strings of the fork back together.
15. The red ABC stop sign says, "Stop all outputs".
16. The Red Jump icon says, "Jump to the Red Land place in the program".
17. The red light says, "End the program".

Congratulations your team has completed the mission successfully!

Name______________________________ Date________________________

Journal: The Gadget

1. Choose one pre-written program that was written for your vehicle and tell what it told the robot to do? (If it has more than 1 step tell what all steps tell the robot to do.)

2. How did you re-write the program?

3. Did your program cause the robot to act as you expected? Explain.

4. Were you a programmer or a builder for your group? Do you like your job? Why or why not?

5. Did working in a group make your job easier? Why or why not?

Mission: "Torbot"

Mission Goal: To construct and program a vehicle using and use motors, touch sensors. To explore the effectiveness of wheels and tank tread for movement.

Materials: RCX brick, IR transmitter, kit including all the Lego parts that you need to complete your mission.

Caution: You are responsible for returning every LEGO piece (in working condition) at the end of every class. Handle sensors and wires gently. They are delicate pieces of electronic scientific equipment.

Part 1: In this part of the mission you will learn how to program and control motors and touch sensors.

Procedure:

1. Construct the vehicle according to the directions on pages 3-10. Make sure that you handle the motors and sensors carefully. **DO NOT turn the black peg while it is attached to the motor.** It will strip the motor and it will no longer work.
2. Open the Robolab program.
3. Click Run Robolab→ Programmer→Pilot 4→Starter Set→ Torbot.
4. Change the program on the screen to the vehicle program shown on page 11.
5. When you have your vehicle constructed turn on the RCX. Place its IR window in front of the IR transmitter. Click on the white arrow icon in the lower center of the screen to download the program. You will hear a beep and receive a written confirmation that the screen downloaded correctly.
6. Press Run to run your program on the robot. Note the behavior of the robot.

As a team jot down your answers to the following questions. What did the sensor tell the robot to do? Explain how the program controlled the robot's behavior? You can find the answers to these questions on the back of this page. Were you correct?

Answers: The program is a 4-step program. Each step of the program told the robot:

a. The green light said, "Stop".
b. Then turn on the motor connected to Output Port A at power level 5 forward.
c. The red stop sign says there is nothing connected to Output Port B and…
d. Also turn on the motor connected to Output Port C at power level 5 forward.
e. Then, "Wait for the touch sensor connected to Input Port 1 to be pushed in".
f. Then, "Reverse the motor connected to Output Port A at power level 5" and…
g. "Turn the motor connected to Output Port C at power level 5 forward.
h. Then, "Wait for .5 seconds".
i. Then, "Turn both motors forward at power level 5".
j. Then," Wait for the touch sensor connected to Input Port 3 to be pushed in".
k. Then, "Turn the motor connected to Output Port A forward at power level 5 and reverse the motor connected to Output Port C at power level 5".
l. Then, "Wait for 0.5 seconds".
m. Then, "Stop".

Did you get the answer right? Now rewrite the program to make the robot behave differently. Did the robot behave as you expected?

Part 2: In this part of the mission you will learn to use and program a light sensor.

Procedure:

1. Open Inventor Level 4→Theme: Starter Set→ Torbot vi.

   The program that you see on the bottom of page 11 will open.
2. Download the program to the robot and run the program.

As a team, jot downs your answers to the following questions.

1. What did the motor do?
2. What did the sensor tell the robot to do?
3. Explain how the program controlled the robot's behavior.

You can find the answers to these questions on the back of this page. Were you correct?

Answers:

1. What did the motors do? The motors turned the wheels.

2. What did the sensors do? The touch sensor told the robot to change its behavior each time the sensor was pushed.

3. Explain how the program controlled the robot's behavior.

   a. The green light said, "Start the program".
   b. The task-split icon said, "Run multiple tasks simultaneously".
   c. The top task begins with the Red Land icon. It said, "Whenever the Red Jump command is used jump to here."
   d. Then, "Turn on the motor connected to Output Port A forward at full power".
   e. Then, "Wait until the touch sensor connected to Input Port 1 is pushed in".
   f. Then, "Reverse the motor connected to Output Port A and…
   g. Wait for 0.5 seconds".
   h. Then, "Red Jump".
   i. Then, "Stop".
   j. At the same time this is happening another "blue task is occurring.
   k. The Blue Land icon said, "Whenever the Blue Jump command is used jump to here".
   l. Then, "Turn on the motor connected to Output Port C forward at full power".
   m. Then, "Wait until the touch sensor connected to Input Port 3 is pushed in". Then, "Reverse the motor connected to Output Port C and…
   n. Wait for 0.5 seconds".
   o. Then, "Blue Jump".
   p. Then, "Stop".

Did you get the program right? Now re-write this program to make the robot behave differently. Download the program and run it. Were you successful? Did the robot behave as you think is should have?

If you have time vary the surfaces over which the robot travels. Did it appear to move better over some types of surfaces? Try constructing a ramp and have the robot move up it. How does it behave?

Congratulations--Your team has completed the mission successfully!

Name ______________________________ Date ____________________

Journal: Torbot

1. Choose one pre-written program that was written for your vehicle and tell what it told the robot to do? (If it has more than 1 step tell what all steps tell the robot to do.)

2. How did you re-write the program?

3. Did your program cause the robot to act as you expected? Explain.

4. Were you a programmer or a builder for your group? Do you like your job? Why or why not?

5. Did working in a group make your job easier? Why or why not?

Mission: "The Car"

Goal: To explore gear trains, motors, lights, and touch sensors in the construction of a robotic car and to program the behavior of the robot.

Materials: RCX brick, IR transmitter, kit including all the Lego parts that you need to complete your mission.

Caution: You are responsible for returning every LEGO piece (in working condition) at the end of every class. Handle sensors and wires gently. They are delicate pieces of electronic scientific equipment.

Procedure:

Part 1:

1. Construct the vehicle according to the directions on pages 6-14. Make sure that you handle the motors and sensors carefully. **DO NOT turn things while they are attached to the motor.** It will strip the motor and it will no longer work. Open the Robolab program.
2. Click Run Robolab→Pilot 1.
3. Change the program that appears on the screen to look like the program on page 15.
4. Download the program to your robot. Download the program to your robot and run it.
5. As a group decide what the program told your robot to do? Did your robot act as expected? Check the next page to see if your answer is correct.

Answer:

1. What did the program tell your robot to do?
    a. The green light says, “Start the program”.
    b. Then, “Turn on the motor connected to Output Port A in reverse at full power for 6 seconds.
    c. Then, “Stop”.

How did you do? That was pretty easy, how about a little more difficult task?

Part 2: In this part of the mission you will modify the robot and create a multi-step program.

1. Modify the robot according to the directions on pages 15 & 16.
2. Open Robolab→Pilot→ Starter Set→ Car Step2. You will see a 4-step program as shown on page 17.
3. Download and run the program.

As a group decide what the program told the robot to do. Check your answer with the answer on the back of this page.

Answer:

1. Decide what the program told the robot to do.
   The program consists of four steps. Step 1 told the robot:
   a. The green light says, "Start the program".
   b. Then turn on the motor connected to Output Port A forward at power level 5 and
   c. Stop all output from ports B & C".
   d. Then, "Wait for the touch sensor connected to Input Port 2 to be pushed in".

   Step 2:

   e. Then, "Reverse the power to the motor connected to Output Port A to power level 1 and stop all output from Port B and turn on the lamp connected to Output Port C at brightness of five".
   f. Then, "Wait for the touch sensor connected to power level 2 to be pushed in".

   Step 3:

   g. Then, "Change the motor connected to Output Port A to forward at power level 3 and stop all outputs from Output Ports B & C".
   h. Then, "Wait for 4 seconds".

   Step 4:

   i. Then "Reverse the motor connected to Output Port A at power level 5 and turn on the lamp connected to Output Port C at brightness 5".
   j. Then, "Wait for the touch sensor connected at power level 2 to be released".
   k. Then, "Stop".

Did you understand what the program said? Let's try another.

Part 3:

1. Modify the robot according to the instructions on pages 18, 22, & 23.
2. Open a new program by clicking on Inventor 2→Starter Set→ Car Step 3.
3. The program you see on page 23 will open.
4. Download the program to your robot. Run it.
5. What did the program tell the robot to do? Formulate your answer with your group. Check it on the back of this page.

Answer:

1. What did the program direct the robot to do?
    a. The green light said, "Start the program".
    b. Then, "Reverse the motor connected to Output Port A at power level 2 and turn on the lamp connected at Output Port C at power level 5".
    c. Then, "Wait until the touch sensor connected at Input Port 1 is pushed in".
    d. Then, "Turn the motor connected at Output Port A forward at power level 5".
    e. Then, "Turn on the lamp connected at Output Port C to power level two for 10 seconds".
    f. Then, "Stop all outputs".
    g. Then, "Stop the program".

Change the program to change the robot's behavior. Download and run your new program. Did the robot perform as you think it should have?

Only one more part and your mission will be complete.

Part 4: In this part of the mission you'll program the car to make a sound and learn to place forks in a program. The fork allows the program to choose a path depending on the state of a touch sensor.

1. Modify the car as shown on page 24.
2. Open a new program by clicking on Inventor 3→ Starter set→ Car step 4. A window showing a similar program to the one on page 25 will open.
3. Change the program so that it is the same as the one on page 25.
4. Download this program to your robot and run the program.
5. Answer the following question with your group. What does the program tell the robot to do? Check your answer with the answer on the back of the page.

Answer: What does the program tell the robot to do?

a. The green light says, "Start the program".
b. The Red Land arrow tells the program where it is to jump when the Red Jump command is used.
c. The Touch Sensor Fork says, "Choose between one of two paths depending on the state of the touch sensor. If the Touch sensor is released, the program follows the top string. If the touch sensor is pushed in, the program follows the bottom string.
d. The top string says, "When the touch sensor is released turn on the motor connected to Output Port A in reverse and play sound 4 and light the lamp connected to Output Port C for 4 seconds".
e. The bottom string says, "Turn on the motor connected to Output Port A forward".
f. The Fork Merge Icon (sideways Y) says, "Merge the two strings of the fork together".
g. Then, "Red Jump back to the Red Land".
h. Then, "Stop".

Experiment with modifying the car and experimenting with the programming if you still have time.

Congratulations! Your team has successfully completed the mission.

Name______________________________ Date_________________

Mission: Car Journal

1. What program did you re-write for the car? (Write the program).

2. How did the program change the robot's behavior?

3. Did the robot act as you expected it to? Explain.

4. Were you a programmer or builder for your group? Did you like your job? Why or why not?

5. Did working in a group make your job easier? Explain.

Mission: "Human Habitat Challenge"

Mission Goal: Your engineering team has been chosen to construct the habitat for a group of colonists scheduled to land on Mars. Your team has arrived at the construction site with plans in hand and awaits the arrival of the ship carrying the materials. Unfortunately, the ship crash-lands at the site and most of the construction materials are destroyed. The colonists will still arrive on schedule and need a place to live. Your mission is to construct a habitat from the parts scavenged from the crash site.

Materials: RCX brick, IR transmitter, kit including all the Lego parts that you need to complete your mission.

Caution: You are responsible for returning every LEGO piece (in working condition) at the end of every class. Handle sensors and wires gently. They are delicate pieces of electronic scientific equipment.

Part 1: In this part of the mission you decide what habitat can be constructed from the materials you have. Luckily you have the original plans (mission technical specifications) to guide your construction. You must also decide how the electronic sensors you have can best be used in the operation of the habitat. Working sensors include one motor, one light, one light sensor, and one touch sensor.

Procedure:

1. Take your time in planning the habitat. Work with the Robolab program so that you can make the best use of your materials.
2. Construct the habitat according to your plan. Make sure that you handle the motor carefully. **DO NOT turn the black peg while it is attached to the motor.** It will strip the motor and it will no longer work.
3. Open the Robolab program.
4. Click Run Robolab→ Programmer→Pilot or Inventor. Use either the Pilot or Inventor programs to write a program to control your light, motor, and sensors. Use the mission technical specifications for guidance but feel be creative in the design of the program.
5. When you have your house constructed, and the program written, turn on the RCX. Place its IR window in front of the IR transmitter. Click on the white arrow icon in the lower center of the screen to download

the program. You will hear a beep and receive a written confirmation that the screen downloaded correctly.

6. To check the program, gently lift the motor/table unit from the floor.
7. Press Run to run the program you created on the robot. Did your program work as you expected? If not troubleshoot the program and habitat and retry the program.
8. Use the digital camera to take a photo of the habitat you engineered and record the program that you wrote in your journal.

Task 2:

1. Try to improve on your habitat design by creating a new one.
2. Photograph and record the new program in your journal.

Congratulations your team has completed the mission successfully!

Name________________

Team________________

Date_________________

Journal: "Human Habitat Challenge"

A Challenge Project

1. What was the first program that you wrote?

2. How did you improve the second habitat?

3. Record the second program that you wrote.

4. Did you find it easy or difficult to design the habitat without plans to follow?

5. Did you find it easy or difficult to write the programs?

6. Was your primary job on your team a builder or a programmer? Did you like that job?

7. Did you assist the engineers on your team who had the other type of job?

8. Whose job appeals to you more—builder or programmer? Why?

Mission: "The Bug"

A Challenge Project

Mission Goal: In this mission your team will construct and test a robotic bug. You might be surprised to find that he mutated from the original design. Can you find the mutation and make the bug move. You will also learn about robots that walk

Materials: RCX brick, IR transmitter, kit including all the Lego parts that you need to complete your mission.

Caution: You are responsible for returning every LEGO piece (in working condition) at the end of every class. Handle sensors and wires gently. They are delicate pieces of electronic scientific equipment.

Procedure:

Construct the robot according to the directions on pages 6-14 of the technical specifications manual. Look carefully at the parts so that you can find the mutation and construct the robot with the different parts you have.

By this time you've completed at least 2 robots and understand how the program works

Program the robot as directed on page 15 of the technical specifications manual. Test the program and see if it works as you expected. Did it? If not troubleshoot the robot and programming and try again. After completing part 1 modify the robot and try part 2. Do the same with parts 3 and 4.

With remaining time practice re-designing the robot and writing your own programs.

Congratulations your team has completed the mission successfully!

Name________________

Team________________

Date_________________

Journal: "The Bug"

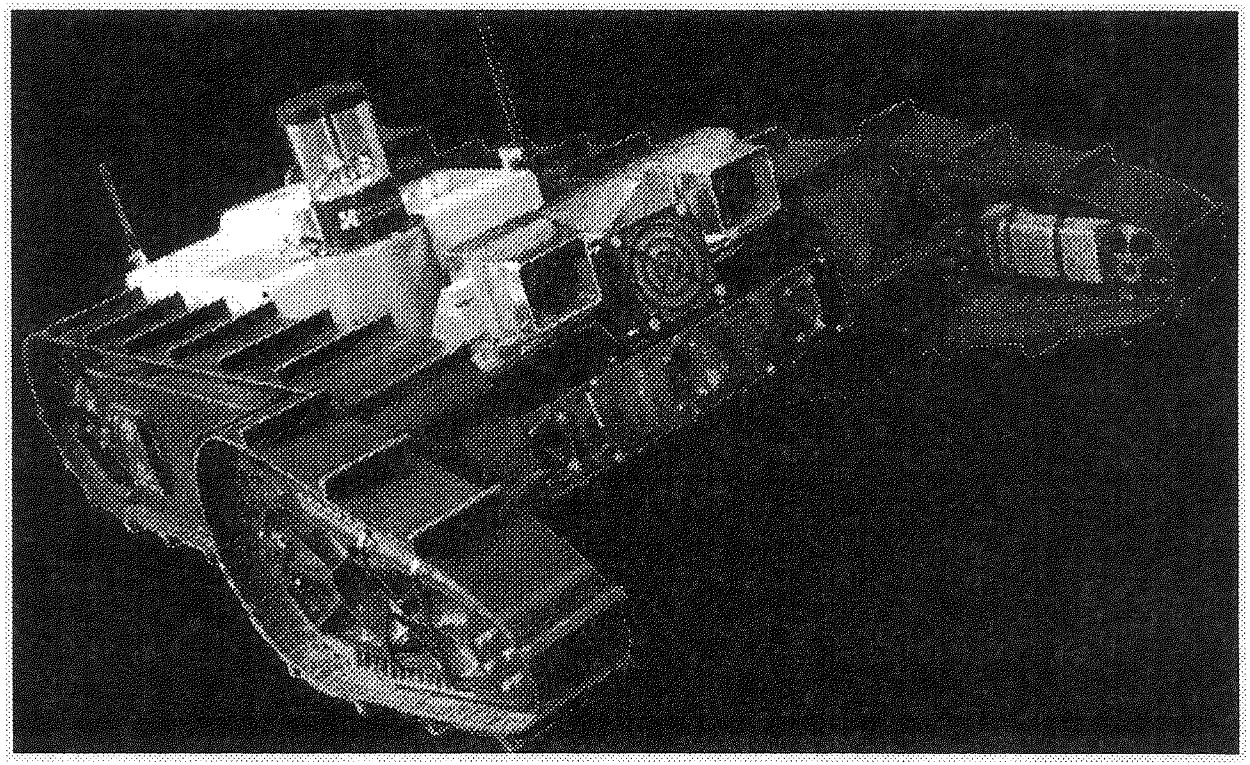
1. What was the mutation?

2. Were you successful in using the "mutated" parts to get the robot to move?

3. Record the best program that you wrote.

Appendix I: The Problem Solving Process.

The Problem Solving Process



Background and picture courtesy of NASA: http://apod.gsfc.nasa.gov/apod/ap960416.html

Steps in Solving a Problem

- Understand the problem.
- Devise a plan.
- Carry out the plan.
- Look back and reflect.

Understand the problem.

- **Know what you are doing and why you are doing it.**
- **Rewrite the problem in your own words.**
- **What is Sojourner's problem?**

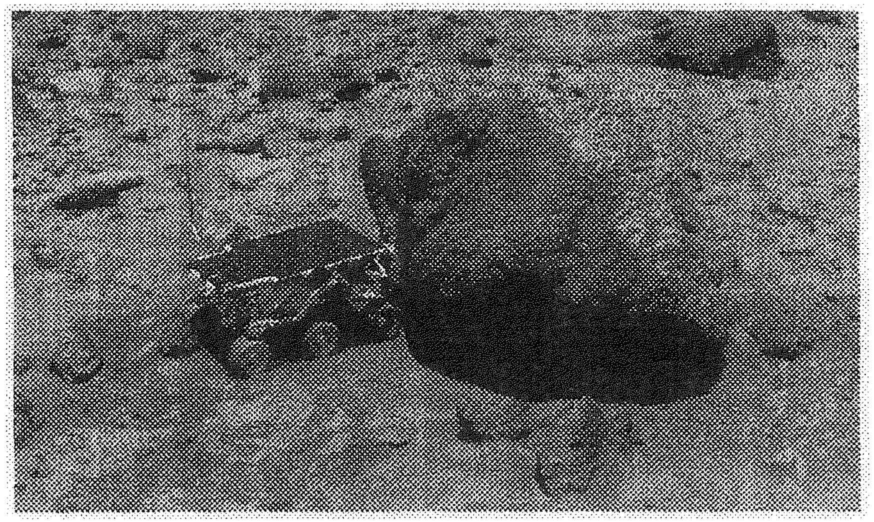


Image courtesy of NASA:
http://nssdc.gsfc.nasa.gov/planetary/image/marspath_yogi_rov.jpg

Devise a plan to solve the problem.

- If it is big, break it down into little problems.
- Work as a team; brainstorm ideas.
- Don't be afraid that your ideas will sound silly.
- Treat everyone's suggestions with respect.

Devise a plan continued…

- Agree on an idea that you think might solve the problem.
- Make an algorithm. This is a detailed sequences of actions written to accomplish a task.
- Have a group member act like the robot performing each step needed to fulfill the task.

Carry out the plan.

- Try your plan and see if it works.
- Does it work as expected?
- Is the problem solved?

Look Back

- **Reflect on work accomplished.**
- **Looking at things that didn't work is as important as looking at things that did work.**
- **If your plan didn't work; revise your plan and test it again.**

Meet Urbie the Jet Propulsion Lab's mobile military reconnaissance robot

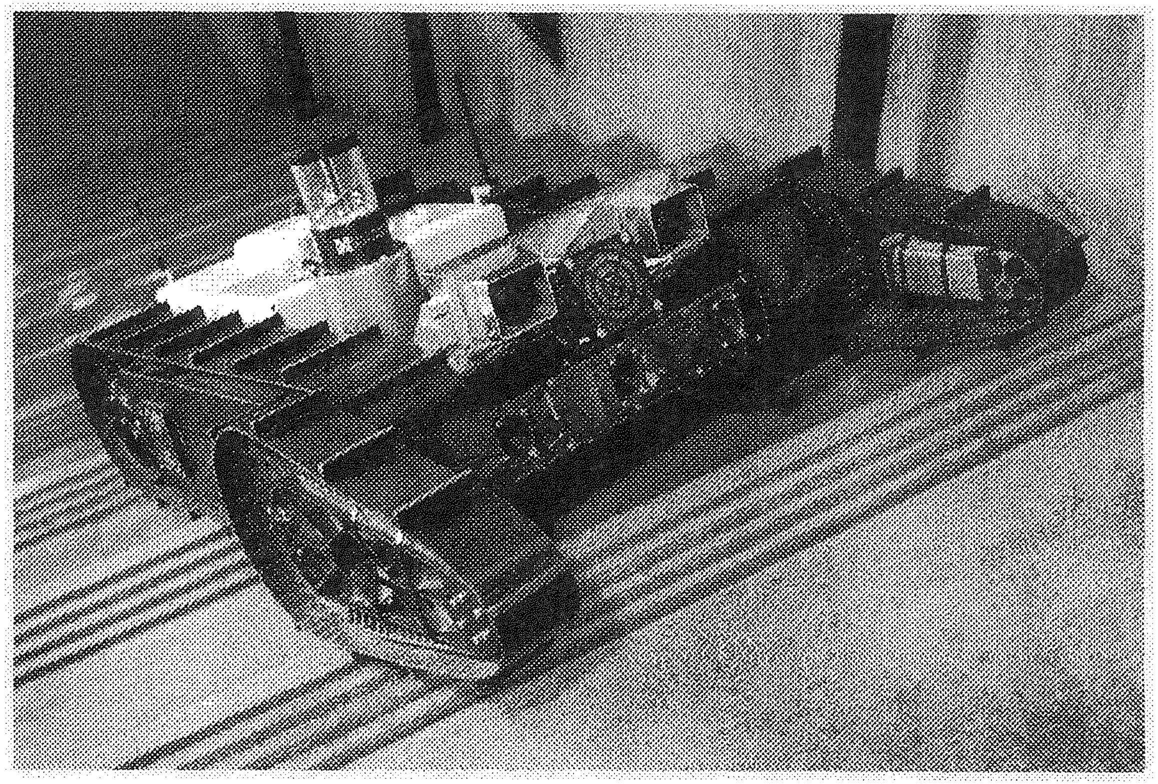
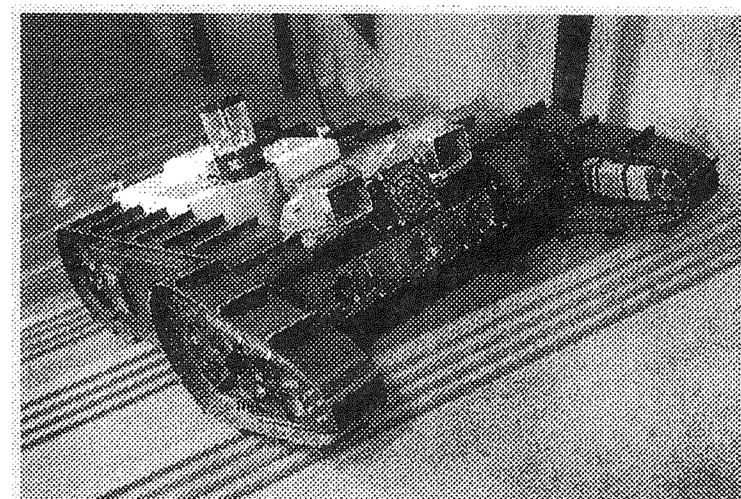


Photo courtesy of NASA: http://robotics.jpl.nasa.gov/tasks/tmr/picts/StairPhoto.jpg

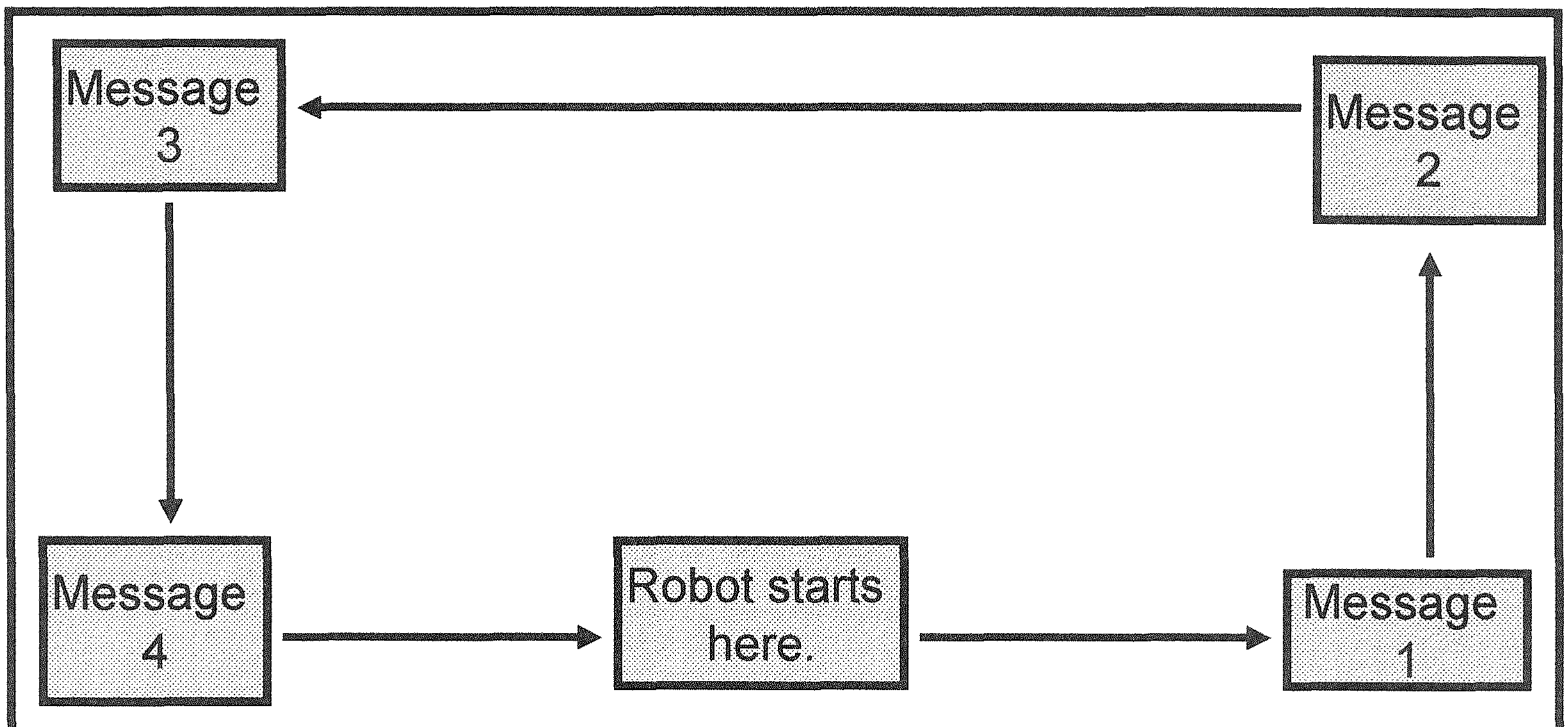
Use your journal and try this...

- Use your imagination and with your group write a simple problem Urbie might need to solve.
- Decide on a plan to solve the problem.
- Write an algorithm to solve the problem.



What's the problem?

- **We've been given the job of making a robot that can go around school and deliver messages.**



Use your journal…

- In your own words write the problem. What must the robot do?

- Devise a plan to have the robot carry out it's job. Include questions that must be answered and an algorithm to use in writing the robot's program.

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